PB80-220627

Environmental Assessment of a Waste-to-Energy Process: Burlington Electric's Wood and Oil Co-Fired Boiler

Midwest Research Inst.
Kansas City, MO

Prepared for

Industrial Environmental Research
Lab.-Cincinnati, OH

Aug 80

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/7-80-148

2.

3. REC
PB80-220627

4. TITLE AND SUBTITLE
Environmental Assessment of a Waste-to-Energy Process: Burlington Electric's Wood and Oil Co-Fired Boiler

5. REPORT DATE
August 1980 Issuing Date.

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Mark A. Golembiewski

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.
EPA 68-02-2166

12. SPONSORING AGENCY NAME AND ADDRESS
Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE
EPA/600/12

15. SUPPLEMENTARY NOTES
EPA Project Officer: Harry M. Freeman (513/684-4363)

16. ABSTRACT

In July 1978, Midwest Research Institute conducted a series of emission tests at the Burlington Electric Department's power plant in Burlington, Vermont. The study was designed to provide multimedia emission data for the purpose of identifying potentially adverse environmental impacts and to identify pollution control technology needs.

The No. 1 boiler at Burlington Electric, which was tested for this study, is fueled by a combination of wood chips and No. 2 fuel oil. Approximately 82% of the heat input (9.3 tons/hr) was provided by the wood fuel and the remaining 18% by the fuel oil (175 gal/hr). Electrical power generated from this boiler system was about 8 MW. The air pollution control system consists of two mechanical collectors in series.

Four effluent streams were sampled and analyzed for this assessment program: bottom ash; primary collector ash; secondary collector ash; and stack emissions. Common to all streams were characterizations for elemental composition and potentially hazardous compounds such as polychlorinated biphenyls and polycyclic aromatic hydrocarbons. In addition, the boiler exhaust gases were analyzed for particulate, NO_x, SO_2, CO, and total hydrocarbon concentrations. The Source Assessment Sampling System was also used, following guidelines established by EPA's Level 1 environmental assessment protocol.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Wood Wastes Environmental Tests Boilers	Wood-Fired Boiler SASS Train SAM-1A Analysis Multimedia Effluent Sampling	

18. DISTRIBUTION STATEMENT Release to public.	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 179
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

EPA-600/7-80-148
August 1980

ENVIRONMENTAL ASSESSMENT OF A WASTE-TO-ENERGY PROCESS

Burlington Electric's Wood and Oil Co-Fired Boiler

by

Mark A. Golembiewski
Midwest Research Institute
Kansas City, Missouri 64110

Contract No. 68-02-2166

Project Officer

Harry M. Freeman
Fuels Technology Branch
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DATE: August 20, 1980

SUBJECT: EPA Camera Ready Copy

FROM: Elaine Cole
CERI, TIOS

PB80 220627

TO: John H. Ashley
Chief, Input Branch
National Technical Information Service

EPA-600/7-80-148 enclosed for inclusion in the NTIS collection.

TITLE: ENVIRONMENTAL ASSESSMENT OF A WASTE-TO-ENERGY PROCESS: Burlington Electric's Wood and Oil Co-Fired Boiler.

The charges for processing are to be assessed against ORD's deposit account 85096 - 6 per agreement between Mr. Cal Lawrence and Mrs. Fran Roberts. (Reference; April 10, 1980 memo.)

If you have any questions, please call me at 513-684-7557.

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

right-hand page

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report documents the results of an environmental assessment of a power plant operated by Burlington (Vermont) Electric Department which is fueled with a combination of wood chips and fuel oil. It discusses, in detail, emissions of criteria and many noncriteria pollutants. It will be of interest to those considering wood as an alternative fuel. Questions and comments should be directed to the Fuels Technology Branch, Industrial Environmental Research Laboratory, Cincinnati, Ohio 45268.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

In July 1978, Midwest Research Institute (MRI) conducted a series of emission tests at the Burlington Electric Department's power plant in Burlington, Vermont. The study was designed to provide multimedia emission data for the purpose of identifying potentially adverse environmental impacts and to identify pollution control technology needs.

The No. 1 boiler at Burlington Electric, which was tested for this study, was fueled by a combination of wood chips and No. 2 fuel oil. Approximately 82% of the heat input (9.3 tons/hr) was provided by the wood fuel and the remaining 18% by the fuel oil (175 gallons/hr). Electrical power generated from this boiler system was about 8 MW. The air pollution control system consisted of two mechanical collectors in series.

Four effluent streams were sampled and analyzed for this assessment program: bottom ash; primary collector ash; secondary collector ash; and stack emissions. The two fuels used were also analyzed. The analysis included identification of elemental compositions, and potentially hazardous compounds, such as polychlorinated biphenyls and polycyclic aromatic hydrocarbons. In addition, the boiler exhaust gases were analyzed for particulate, CO, NO_x, SO_2, and total hydrocarbons. The Source Assessment Sampling System (SASS) was also used, following guidelines established by EPA's Level 1 environmental assessment protocol.

Data obtained from the above tests were used to evaluate each effluent stream on the basis of existing standards and also based on EPA's Source Analysis Model (SAM-1A). Results of the sampling and analysis efforts indicate a total particulate loading of 0.077 gr/scf at the outlet of the control device. The control device demonstrated a particulate collection efficiency of 94%. Average CO concentrations ranged between 180 and 245 ppm; NO_x emissions averaged about 65 ppm; SO_2 averaged between 120 and 155 ppm, and total hydrocarbons were of the order of 10 ppm. Based on the SAM-1A methodology, the secondary collector ash demonstrated the highest degree of hazard.

CONTENTS

Page

Foreword . . . iii
Abstract . . . iv
Figures. . . . vii
Tables . . . ix
Acknowledgment . . . xiii
Summary. . . . xiv

1. Introduction . . . 1
2. Description of the Boiler Facility . . . 2
3. Sampling and Analytical Methodology . . . 6
    - Wood Chip Fuel . . . 6
    - Fuel Oil . . . 11
    - Bottom Ash . . . 11
    - Collector Inlet . . . 12
    - Primary and Secondary Collector Ash . . . 12
    - Collector Outlet . . . 13
    - Chemical Speciation . . . 15
4. Presentation and Discussion of Results . . . 16
    - Boiler Operating Conditions . . . 16
    - Wood Fuel Analysis . . . 17
    - Fuel Oil Analysis . . . 20
    - Bottom Ash . . . 22
    - Uncontrolled Air Emissions (collector inlet) . . . 26
    - Primary and Secondary Collector Ash . . . 32
    - Controlled Air Emissions (collector outlet) . . . 40
    - Opacity . . . 55
    - PCB and PAH Compounds . . . 55
    - SASS - Level 1 Assessment . . . 58
    - Electron Spectroscopy for Chemical Analysis . . . 67
5. Environmental Assessment of Burlington Data Based on EPA's SAM-1A . . . 72
    - Approach . . . 72
    - Burlington Data . . . 74
6. Conclusions . . . 77
    - Bottom Ash . . . 77
    - Primary Collector Ash . . . 77
    - Secondary Collector Ash . . . 78
    - Stack Emissions . . . 78
    - SAM-1A Effluent Analysis . . . 79

CONTENTS (continued)

Page

References 80

Appendices

A. Analytical Methodology 81
B. Sampling Locations and Procedures 120
C. Comparison of Chemical Analyses of Bottom Ash, Primary Ash, and Secondary Collector Ash 135
D. Description of SASS Equipment and Analysis 142
E. Data Tables for SAM-1A 145

FIGURES

No. Page

1 Layout of the Burlington Electric Plant 3
2 Schematic diagram of the wood feed system (one of four chutes). 4
3 Test matrix for Burlington Electric's wood and oil fired power plant 7
4 Inlet particle size distribution - Run 1 33
5 Inlet particulate size distribution - Run 2 34
6 Inlet particle size distribution - Run 3 35
7 Outlet particle size distribution - Run 1 51
8 Outlet particle size distribution - Run 2 52
9 Outlet particle size distribution - Run 3 53
10 Average particle size distributions (inlet and outlet) 54
11 Plot of opacity versus time, 7/24/78 57
12 Plot of opacity versus time, 7/25/78 57
13 Auger survey scan of 1-μ particulate 71
A-1 Reconstructed ion chromatogram for PAH standard 98
A-2 Chromatogram resolution of phenanthrene, anthracene, and D-10 anthracene 99
A-3 Chromatographic resolution of 1,2-benzanthracene and chrysene . 100
A-4 Chromatogram of heterocyclic PAH standard 102
A-5 Identification of fluoranthene and pyrene in secondary collector ash 103
A-6 Organic Level 1 analysis flow diagram 112
A-7 IR spectrum for LC Fraction 6 of XAD-2 resin 115
A-8 Typical TCO chromatogram of concentrated extract from XAD-2 sample 117
A-9 Direct inlet LRMS of concentrated XAD-2 field sample extract . 118
B-1 Layout of Burlington Electric Plant facilities 121
B-2 Example of sampling location for wood feed stream 122
B-3 Illustration of the collector hopper arrangement 124
B-4 Schematic diagram of the inlet sampling location 125
B-5 Schematic diagram of the outlet sampling location 126
B-6 Schematic illustration of Method 5 sampling train in sampling position 128
B-7 Schematic illustration of the MRI dynamic dilution - optical counter particle sizing system 129
B-8 Photograph of the MRI-developed dynamic dilution system 131

FIGURES (continued)

No.		Page
B-9	Photograph of the particle counting system in sampling position	132
B-10	PCB sampling train	133
B-11	Schematic diagram of the SASS train	134
C-1	GC/MS chromatograms for bottom ash, primary collector ash, and secondary collector ash extracts	138
C-2	Photograph of density gradient experiment	140
D-1	Schematic of source assessment sampling system	143

TABLES

No. **Page**

1 Burlington test schedule 6
2 Summary of analysis methods 8
3 Summary of fuel input data 17
4 Summary of boiler operating parameters 18
5 Analysis of wood fuel 19
6 Wood fuel composition reported by Burlington Electric 20
7 Elemental analysis of wood by SSMS 21
8 Analysis of No. 2 fuel oil 22
9 Elemental analysis of fuel oil by SSMS 23
10 Elemental analysis of bottom ash by SSMS 24
11 Analysis of bottom ash for PAH by GC/MS 25
12 Uncontrolled air emissions 26
13 Elemental analysis of inlet Method 5 filter particulate by SSMS 28
14a Air emission concentrations for selected elements in uncontrolled particulate 29
14b Air emission factors for selected elements in uncontrolled particulate 29
15 Inlet particle size distribution by number as monitored by the optical counter 30
16 Inlet particle counts by size as monitored by the diffusion battery/condensation nuclei counter 31
17 Inlet particle size distribution resulting from diffusion battery penetration data 32
18 Elemental analysis of primary collector ash by SSMS concentration 37
19 Elemental analysis of secondary collector ash by SSMS 38
20 Comparison of elemental analysis of ash materials 39
21 Analysis of secondary collector ash for PAH by GC/MS 41
22 Boiler exhaust gas composition 42
23 Summary of particulate test results (metric units) 44
24 Summary of particulate test results (English units) 45
25 Elemental analysis of outlet Method 5 filter particulate by SSMS 47

TABLES (continued)

No. Page

26 Selected elemental concentrations in controlled particulate emissions . . . 48
27 Outlet particle size distribution by number as monitored by the optical counter . . . 48
28 Outlet particle counts by size as monitored by the diffusion battery/condensation nuclei counter . . . 49
29 Outlet particle size distribution resulting from diffusion battery penetration data . . . 50
30 Summary of BAHCO ash analysis . . . 56
31 Simulated particle size distributions developed by UOP . . . 56
32 Analysis of Florisil train components for PAH by GC/MS . . . 59
33 SASS particulate analysis (Level 1) . . . 60
34 Summary of SASS particulate results . . . 60
35 Elemental analysis of SASS aqueous condensate by SSMS . . . 62
36 Elemental analysis of SASS hydrogen peroxide impinger counter by SSMS . . . 63
37 Level 1 organic analytical results . . . 64
38 IR spectral analysis of concentrated XAD-2 resin extract . . . 66
39 Level 1 organic analysis of liquid chromatographic fractions of XAD-2 resin sample . . . 66
40 IR spectral analysis of LC Fractions 6 and 7 . . . 67
41 ESCA results for 1-μ particulate . . . 69
42 ESCA results for bottom ash . . . 70
43 Summary of SAM-1A effluent analysis . . . 74
A-1 Proximate and ultimate blind duplicate analyses of wood and fuel oil . . . 82
A-2 Elemental analysis of NBS SRM 1633 coal fly ash by SSMS . . . 90
A-3 SSMS elemental analysis of NBS pine needles SRM 1575 . . . 92
A-4 SSMS quality assurance analysis of trace metals in oil . . . 93
A-5 SSMS analysis of selected elemental fortifications in aqueous condensate . . . 94
A-6 Elemental analysis of fortified 30% hydrogen peroxide by SSMS . 95
A-7 GC/MS operating conditions for PAH analysis . . . 97
A-8 Quality assurance data for low level PAH fortification of selected samples . . . 104
A-9 GC/MS quality assurance data for selected long retention time PAH compounds . . . 105
A-10 Analytical precision of selected PAH compounds in ash extracts. 106
A-11 Recovery of Arochlor 1254 fortifications from selected samples analyzed by EC/GC . . . 108
A-12 Quality assurance data for GC/MS analysis of PCB fortified samples . . . 109
A-13 Level 1 organic sample summary . . . 113
A-14 LRMS operating conditions . . . 114

TABLES (continued)

No. Page

C-1 Quality assurance data for low level PAH fortification of selected samples 136
C-2 GC/MS quality assurance data for selected long retention time PAH compounds 137
D-1 Analysis matrix for SASS train components 144

METRIC CONVERSION FACTORS USED IN THIS REPORT

To convert from English	To Metric	Multiply by
Btu	kJ	1.055
Btu/lb	kJ/kg	2.326
ft	m	3.048 E-01
ft^2	m^2	9.290 E-02
ft^3/min	m^3/min	2.832 E-02
gal/min	liter/min	3.785
gr/scf	g/dscm	2.288
lb	kg	4.536 E-01
lb/ft^3	kg/m^3	1.603 E-01
$lb/10^6$ Btu	kg/MJ	4.300 E-01
psi	kPa	6.895
ton	Mg	9.072 E-01

ACKNOWLEDGMENT

This report was prepared as partial fulfillment of Environmental Protection Agency Contract No. 68-02-2166. The overall program, "Environmental Assessment of Waste-to-Energy Processes," is managed by Mr. M. P. Schrag and the project leader is Dr. K. P. Ananth. The principal author of this report was Mr. Mark Golembiewski. The author is grateful for the assistance of Dr. Glenn Trischan, who supervised the analytical work, authored the appendix on analysis methodology, and provided a great deal of interpretive input. Mr. Emile Baladi is also recognized for his supervision of the field sampling activities.

Midwest Research Institute would like to express its sincere appreciation for the generous assistance and cooperation provided by Mr. Thomas Carr, Superintendent of the Burlington plant, and his operating staff throughout this test program.

SUMMARY

The sampling study described in this report was conducted at the Burlington Electric Department plant in Burlington, Vermont, during July 1978. The objective was to provide information which would help define the hazard potential of each effluent stream and identify control technology needs. The test program and results are summarized below.

The No. 1 boiler at Burlington Electric has been modified to burn a combination of wood chips and No. 2 fuel oil and produces sufficient steam to power an electrical generator rated at 10 MW. Wood is the primary fuel and oil is used as a supplementary fuel to maintain steam production near maximum capacity. Air emissions are controlled by two mechanical collectors in series. Bottom ash and fly ash collected by the particulate control system are pneumatically conveyed to a storage silo before being transported to a landfill.

Fuel feed and effluent streams sampled for this environmental assessment program included:

- Wood chip feed;
- Fuel oil feed;
- Bottom ash;
- Primary collector ash;
- Secondary collector ash; and
- Stack emissions (collector outlet).

No wastewater streams were associated with the Burlington boiler.

Three complete sets of samples from each of these streams were taken over a 2-day period. Sample analyses included conventional pollutants plus elemental composition and selected hazardous materials (polychlorinated biphenyls - PCB, and polycyclic aromatic hydrocarbons - PAH). In addition, a modified Level 1 assessment was carried out using the Source Assessment Sampling System (SASS).

The Level 1 analysis protocol included determinations for particulates, organic constituents and vaporous metals. Major findings of the study, plus brief descriptions of the test methods, are summarized below in the order of the input/output streams listed above.

SYSTEM OPERATING PARAMETERS

Wood chips (roughly 3-cm square) are pneumatically injected into the boiler and onto a traveling grate at a rate of about 9 tons/hr. The supplementary fuel oil (approximately 175 gal/hr) is fired from the sides, several feet above the grate. The wood/oil feed ratio during the Midwest Research Institute (MRI) tests was approximately 80% wood - 20% oil, on a heat input basis. A slightly higher ratio was used on the second test day. Total heat input to the boiler averaged about 140 x 10^6 kJ/hr (135 x 10^6 Btu/hr).

WOOD FEED

Grab samples of wood chips were taken from the feeder system during each of the three test runs. Sample analyses included moisture content determination, proximate and ultimate analyses, and assessment of heating value. Elemental composition of the wood was also determined. Results of the proximate analysis indicated an average composition of 4.3% ash, 70.0% volatile matter, and 25.7% fixed carbon (dry basis). The average sulfur content was 0.35% and the average heat of combustion (as received) was 13,650 kJ/kg (5,870 Btu/lb). On a dry basis, the heating value was 22,040 kJ/kg (9,480 Btu/lb).

OIL FEED

One grab sample of No. 2 fuel oil was collected for each day of testing. Heat of combustion and elemental composition were determined. The samples also underwent ultimate analysis. Sulfur content of the oil was 0.35%, while its heat of combustion averaged 45,400 kJ/kg (19,500 Btu/lb or 138,300 Btu/gal).

BOTTOM ASH

Three composited samples of the bottom ash were obtained for subsequent analysis. Determinations were made for elemental composition and PCB and PAH material content. As expected, most elements were more concentrated in the bottom ash relative to the fuel inputs. Those elements exhibiting the largest increases in concentration included Ba, Zr, Sr, and Li.

No PCB materials could be detected in the bottom ash samples above the 0.05 µg/g detection limit. One PAH compound, phenanthrene, was identified at an average concentration of 0.89 µg/g.

The amount of bottom ash generated during the MRI test program was estimated to be about 91 kg/hr (200 lb/hr). On a dry weight basis, slightly less than 2% of the wood fuel input was discharged as bottom ash.

UNCONTROLLED AIR EMISSIONS

Particulate concentrations in the boiler exhaust gases before the control device were determined by completing three Environmental Protection Agency (EPA) Method 5 runs. The resulting average concentration was 2.96 g/dscm (1.30 gr/dscf). On the basis of heat input, uncontrolled particulate emissions averaged 1.47 g/MJ (3.43 lb/10^6 Btu). Oxygen and carbon dioxide contents were monitored during the particulate runs and averaged 12.3% and 8.2%, respectively.

Filter samples from the Method 5 particulate tests were analyzed for elemental composition. The elements emitted at concentrations greater than 10 μg/dscm were Pb, Ba, Sr, As, Ga, Zn, Cu, Fe, Mn, Ti, and P.

An optical/diffusional particle counting system was used to measure the particle size distribution of the uncontrolled emissions. Three runs using this system were made. Particles in the range of 0.005 to 0.10 μm were counted by a diffusion battery/condensation nuclei counter arrangement, while those in the 0.3 to 2.6 μm range were counted by an optical counter. Because the dilution system consistently became plugged with larger particles during operation, no particle counts could be obtained in the size region above 2.6 μm. Therefore, the mean particle size could not be determined. Within the size range of particles counted (0.005 to 2.6), the majority of the particles appeared to be between 0.3 and 0.5 μm in diameter.

PRIMARY AND SECONDARY COLLECTOR ASH

Grab samples of collected fly ash were taken from the hoppers beneath the primary and secondary mechanical collectors. The samples were analyzed for elemental composition and for concentrations of PCB and PAH compounds. In general, the elements detected at the highest concentrations in the primary and secondary collector ashes were the same elements that were most prominent in the bottom ash. Furthermore, many elements were more concentrated in the secondary ash relative to the primary ash. Several elements showed a trend of increasing concentration from bottom ash to primary collector ash to secondary collector ash. These included Hg, Br, Se, As, Cl, F, and B.

Analysis for PCB materials did not yield any positive responses above the 0.05 μg/g detection limit in either of the ash samples. No PAH compounds were identified in the primary ash sample extracts. However, several compounds were confirmed in the secondary ash samples, including acenapthylene, phenanthrene, fluoranthene, and pyrene. One sample contained 10 μg/g of phenanthrene, which was the highest PAH concentration observed.

CONTROLLED AIR EMISSIONS

Using continuous gas analyzers, concentrations of O_2, NO_x, SO_2, CO, and total hydrocarbons (THC) were measured in the boiler exhaust stream. NO_x and SO_2 concentrations averaged 66 and 138 ppm, respectively. CO readings averaged 213 ppm. THC concentrations averaging only 9 ppm were observed.

Three Method 5 particulate runs were made simultaneously with the sampling runs at the collector inlet. The average particulate concentration was 0.18 g/dscm (0.08 gr/dscf). The particulate emission rate averaged 0.09 g/MJ (0.17 lb/10^6 Btu), on the basis of heat input. The average efficiency of the two-stage mechanical collection system, as determined from the simultaneous inlet/outlet tests, was 94.2% for total particulate and 95.1% for filterable particulate only. Visual plume opacity readings taken during testing indicated an average opacity of about 20%.

Elemental analysis of the Method 5 particulate filters indicated moderately high elemental concentrations. Pb, Ba, Sr, Zn, and Ti were present at the highest concentrations, approaching 100 μg/dscm, while Hg, Sb, Zr, Br, Se, As, Ga, Cu, Ni, and V were in the range of 1 to 75 μg/dscm. The remaining elements had concentrations which were less than 1 μg/dscm.

Particle size data were obtained by the same method used at the collector inlet (optical/diffusional particle counter). As with the inlet measurements, data for particles > 2.6 μm in diameter could not be obtained. The number of small particles (< 2.6 μm) appeared to increase in the controlled gas stream relative to the uncontrolled emissions. The reasons for this increase are not clear.

Plume opacity data, obtained using EPA Method 9, averaged about 20% on both test days. Samples for analysis of PCB and PAH materials were collected in a special sampling train utilizing impingers and a Florisil adsorbent trap. Two sampling runs were made with this collection system and the samples were split for the two, separate analyses. PCB analysis did not produce any responses greater than the 1 μg/sample detection limit of the GC/MS analytical technique. Similarly, no PAH compounds were identified at levels which permitted structural confirmation.

Organic analysis of the SASS components, in accordance with Level 1 guidelines, revealed low levels of organic constituents. Characterization of the organic emissions was difficult, although they appeared to be composed mainly of carbonyl-containing groups.

SOURCE ASSESSMENT MODEL (SAM-1A)

The EPA's SAM-1A methodology was applied to the four effluent streams as a means of interpreting the emission measurement results. The SAM-1A analysis indicated that the secondary collector ash contained the highest degree of hazard, although all three ash streams were similar in the magnitude of their hazard values. These values were primarily the result of just a few elements which had low Minimum Acute Toxicity Effluent (MATE) values assigned to them. Considerations of the physical nature of the ash discharges and the actual disposal conditions could substantially reduce the true hazard potential of these streams from that estimated by the SAM-1A methodology. Stack emissions showed a relatively low degree of hazard.

The primary collector ash stream had the highest Toxic Unit Discharge Rate (TUDR) which would seem to indicate that this effluent should receive the first priority for control measures. However, for the reasons discussed above, further work is needed to provide a better estimation of the environmental control needs.

right-hand page

SECTION 1

INTRODUCTION

The environmental assessment of Burlington Electric's wood and oil fired boiler described in this report is one of a series of similar field studies performed by MRI under contract to EPA's Industrial Environmental Research Laboratory, Fuels Technology Branch, in Cincinnati. Other waste-to-energy systems studied to date have included a wood and coal fired boiler, an air classifier at a refuse processing plant, a refuse-fed pyrolysis reactor, and a waterwall refuse incinerator. (1-4)

Because of renewed interest in the use of wood and wood waste as a primary boiler fuel in certain regions of the country, the Burlington Electric plant was selected for inclusion in the EPA/MRI environmental assessment program. The Burlington facility is the only one in the United States that is presently firing oil with wood waste to generate electric power.

The following sections of this report contain a description of the test facility, an overview of the sampling and analytical procedures used, and a discussion of the results of the test program. An assessment of these results by applying EPA's SAM-1A and a summary of the study's major findings are also included.

SECTION 2

DESCRIPTION OF THE BOILER FACILITY

The No. 1 unit at Burlington Electric's J. Edward Moran Generating Station was originally a coal fired boiler which has been modified to accommodate a wood fuel (chips) with supplementary oil injection. Steam production is rated at 45,360 kg/hr (100,000 lb/hr), which powers a 10 MW turbine generator. Tandem mechanical collectors are used for emission control. Figure 1 shows a layout of the plant and storage yard.

Wood chips from the storage pile are pushed by bulldozer into a ground-level feed conveyor hopper. Because of an adjacent coal storage pile, small amounts of coal fines are invariably mixed with the wood chips. Through a series of conveyors, the chips are brought to a storage bin near the No. 1 boiler. Four parallel screw conveyors continuously remove wood chips from the bottom of the storage bin and transfer them to four gravity-fed chutes. Compressed air is used at the base of the chutes to inject the chips into the boiler and to prevent clogging in the chutes. A schematic of the feed system is shown in Figure 2.

The wood chips fall onto a horizontal, traveling grate which is supplied with underfire air. Because of the high moisture content of the chips, the boiler cannot provide the desired steam output based on wood alone. Therefore, supplementary fuel oil (No. 2), along with overfire air, is introduced above the grate bed from both sides of the firebox, thus insuring adequate steam production. Residual ash is discharged at the end of the grate into a hopper and then is pneumatically transferred to an outdoor storage silo.

During the MRI tests, the fuel blend ratio, on a Btu input basis, was approximately 82% wood chips and 18% fuel oil. The corresponding feed rates were roughly 8.2 Mg/hr (9 tons/hr) and 660 liters/hr (175 gal/hr), respectively. Under these firing conditions, the No. 1 boiler produced about 40,800 kg/hr of steam (90% of rated capacity).

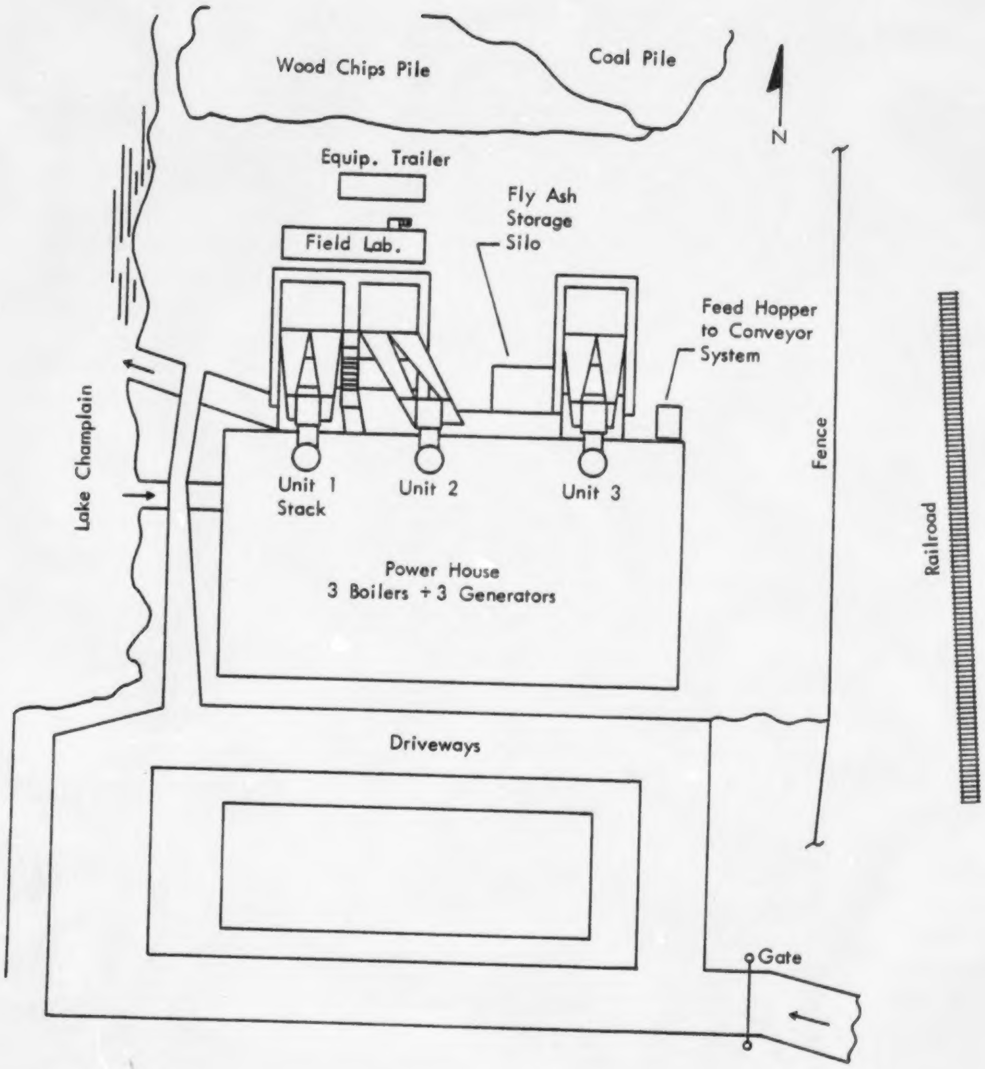

Wood Chips Pile
Coal Pile
N
Equip. Trailer
Field Lab.
Fly Ash Storage Silo
Feed Hopper to Conveyor System
Lake Champlain
Unit 1 Stack
Unit 2
Unit 3
Fence
Railroad
Power House
3 Boilers + 3 Generators
Driveways
Gate

Figure 1. Layout of the Burlington Electric Plant.

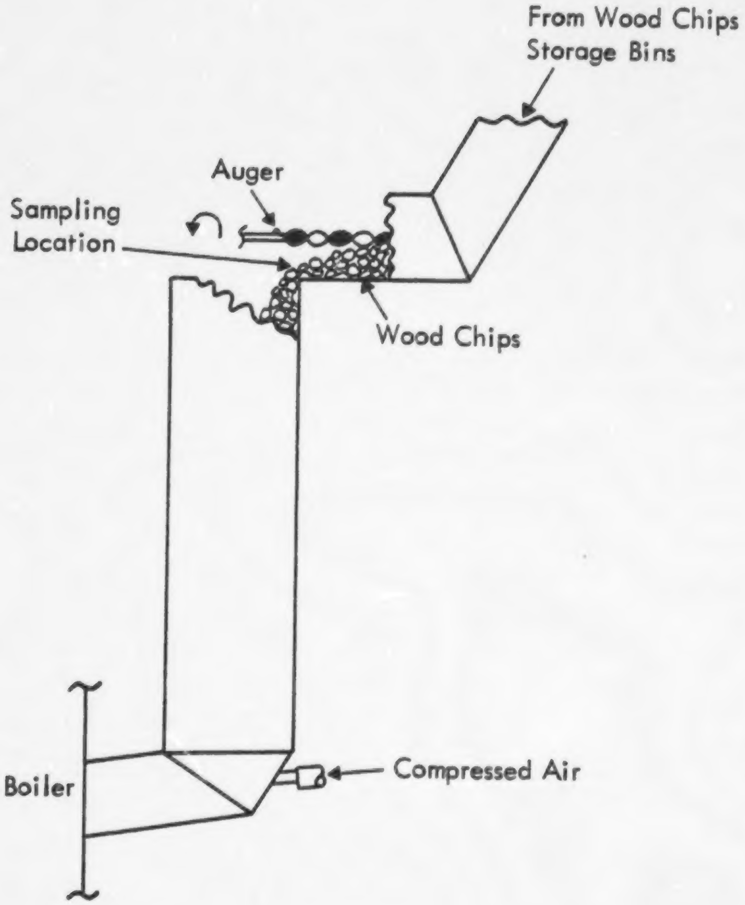

From Wood Chips
Storage Bins
Auger
Sampling
Location
Wood Chips
Boiler
Compressed Air

Figure 2. Schematic diagram of the wood feed system (one of four chutes).

The boiler was supplied by the Wickes Boiler Company and has a furnace volume of 170 m^3. A waterwall surface area of 216 m^2 precedes the boiler tubes and an economizer section follows. The design steam output specifications are 6,200 kPa at 438°C (900 psig at 820°F).

Flue gases, after leaving the economizer section, are ducted to an emission control system which consists of two, high efficiency mechanical collectors in series. The units were supplied by Union Oil Products (UOP)/Air Correction Division. Each collector contains 260, 15.2 cm diameter tubes in a 13 by 20 array. For a flue gas flow rate of 1,700 acmm at 166°C (60,000 acfm at 330°F), the collectors were designed for an overall pressure drop of 16.5 cm H_2O and a collection efficiency of 97.75%.

After exiting the collectors, the flue gases enter an ID fan and are discharged through the No. 1 unit's exhaust stack. Exhaust flow rates are of the order of 1,275 dscmm (45,000 dscfm).

Fly ash collected by the control system is pneumatically conveyed to a storage silo and later transported by truck to a landfill.

SECTION 3

SAMPLING AND ANALYTICAL METHODOLOGY

The sampling program conducted at the Burlington Electric facility was designed to provide environmental assessment data by characterizing all effluent streams from the boiler system. The two fuels used were also sampled and analyzed to allow comparison with the effluent streams. Figure 3 presents the test matrix followed for the Burlington program.

The sampling chronology is shown in Table 1.

TABLE 1. BURLINGTON TEST SCHEDULE

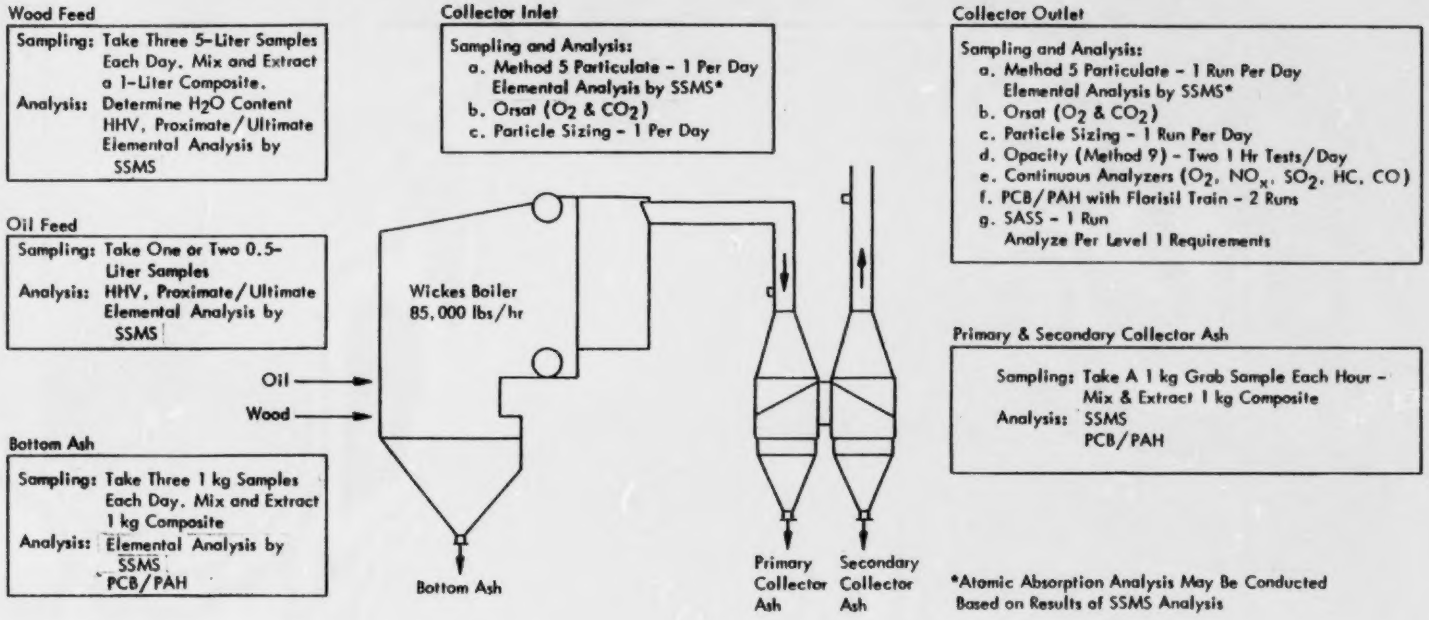
Test No.	Date	Test period	Comments
1	7/24/78	11:08-17:32	Included both PCB/PAH runs[a]
2 and 3	7/25/78	08:20-19:57	Included SASS run[a]

[a] In addition, sampling was done for total particulate, particle sizing, and gases.

A summary of the laboratory analyses performed on each sample, and the methodologies used, is shown in Table 2. Detailed descriptions of the analytical procedures are contained in Appendix A. The sampling and analysis schemes used for each of the effluent streams are discussed next.

WOOD CHIP FUEL

For each of the three tests, a sample of the wood chips was obtained from the feed augers just prior to the wood supply chutes. A long-handled scoop was used to extract a sample from each of the four augers.



Wood Feed

Sampling: Take Three 5-Liter Samples Each Day. Mix and Extract a 1-Liter Composite.
Analysis: Determine H_2O Content HHV, Proximate/Ultimate Elemental Analysis by SSMS

Oil Feed

Sampling: Take One or Two 0.5-Liter Samples
Analysis: HHV, Proximate/Ultimate Elemental Analysis by SSMS

Bottom Ash

Sampling: Take Three 1 kg Samples Each Day. Mix and Extract 1 kg Composite
Analysis: Elemental Analysis by SSMS PCB/PAH

Collector Inlet

Sampling and Analysis:
- a. Method 5 Particulate - 1 Per Day Elemental Analysis by SSMS*
- b. Orsat (O_2 & CO_2)
- c. Particle Sizing - 1 Per Day

Collector Outlet

Sampling and Analysis:
- a. Method 5 Particulate - 1 Run Per Day Elemental Analysis by SSMS*
- b. Orsat (O_2 & CO_2)
- c. Particle Sizing - 1 Run Per Day
- d. Opacity (Method 9) - Two 1 Hr Tests/Day
- e. Continuous Analyzers (O_2, NO_x, SO_2, HC, CO)
- f. PCB/PAH with Florisil Train - 2 Runs
- g. SASS - 1 Run Analyze Per Level 1 Requirements

Primary & Secondary Collector Ash

Sampling: Take A 1 kg Grab Sample Each Hour - Mix & Extract 1 kg Composite
Analysis: SSMS PCB/PAH

*Atomic Absorption Analysis May Be Conducted Based on Results of SSMS Analysis

Figure 3. Test matrix for Burlington Electric's wood and oil fired power plant.

TABLE 2. SUMMARY OF ANALYSIS METHODS

Sample	Parameter	Analytical method
Fuel oil	Proximate	
	Moisture	Modified ASTM Method D-3172-73
	Ash	
	Volatile matter	
	Fixed carbon	
	Sulfur	
	Heat of combustion	
	Ultimate	
	Hydrogen	Modified ASTM Method D-3176-74
	Carbon	
	Nitrogen	
	Oxygen	
	Elemental composition	Spark source mass spectrometry and atomic absorption spectrometry (Hg)
Wood	Proximate	
	Moisture	Modified ASTM Method D-3172-73
	Ash	
	Volatile matter	
	Fixed carbon	
	Sulfur	
	Heat of combustion	
	Ultimate	
	Hydrogen	Modified ASTM Method D-3176-74
	Carbon	
	Nitrogen	
	Oxygen	
	Elemental composition	Spark source mass spectrometry and atomic absorption spectrometry (Hg)

(continued)

TABLE 2. (continued)

Sample	Parameter	Analytical method
Bottom ash	Elemental composition	Spark source mass spectrometry
	Polynuclear aromatic hydrocarbons	Gas chromatography/mass spectrometry
	Polychlorinated biphenyls	Gas chromatography/mass spectrometry and electron capture gas chromatography
	Chemical speciation	Electron spectroscopy for chemical analysis
Collector inlet	Particulate mass	EPA Method 5
	Moisture content	EPA Method 5
	$O_2 + CO_2$	Orsat/Fyrite
	Particle sizing	Particle counting system (optical)
	Elemental composition	Spark source mass spectrometry and atomic absorption spectrometry (Hg)
Primary collector ash	Elemental composition	Spark source mass spectrometry and atomic absorption spectrometry (Hg)
	Polynuclear aromatic hydrocarbons	Gas chromatography/mass spectrometry
	Polychlorinated biphenyls	Gas chromatography/mass spectrometry and electron capture gas chromatography
Secondary collector ash	Elemental composition	Spark source mass spectrometry and atomic absorption spectrometry (Hg)
	Polynuclear aromatic hydrocarbons	Gas chromatography/mass spectrometry
	Polychlorinated biphenyls	Gas chromatography/mass spectrometry and electron capture gas chromatography

(continued)

TABLE 2. (continued)

Sample	Parameter	Analytical method
Collector outlet	Particulate mass	EPA Method 5
	Moisture content	EPA Method 5
	$O_2 + CO_2$	Orsat with O_2 also determined by continuous analysis
	Particle sizing	Particle counting system (optical)
	Opacity	EPA Method 9
	Gases	
	SO_2	Continuous monitors
	NO_x	
	CO	
	O_2	
	HC	
	Level 1	
	Particulate sizing	SASS - Level 1 gravimetric
	Organic	SASS - Level 1 gravimetric, gas chromatography, infrared, liquid chromatography, and mass spectrometry
	Elemental composition	Spark source mass spectrometry and atomic absorption spectrometry (Hg)
	Chemical speciation	Electron spectroscopy for chemical analysis and auger electron spectroscopy

This was done three times during each test and the collected chips were placed in a plastic bag. At the end of each test, the chips were thoroughly mixed and a 1-liter sample was withdrawn and placed in a glass jar.

In the laboratory, the wood samples were first dried at a temperature slightly above ambient to remove the "free" moisture. The samples were then ground and submitted for proximate and ultimate analysis. The fuel's heating value was also determined. Another portion of each sample was analyzed by Spark Source Mass Spectrometry (SSMS) to determine elemental composition.

The quantity of wood chips fed to the boiler each hour was determined using a counting mechanism connected to the shafts of the augers. The number of revolutions were totaled each hour by plant personnel and translated into pounds of wood chips using previously determined calibration data.

FUEL OIL

Fuel oil samples were drawn from a tap in the oil feed line near the point of injection into the boiler. A 1-liter sample was collected on each of the 2 days of testing.

As with the wood chips, the fuel oil was subjected to ultimate analysis and determination of heat of combustion. In addition, an elemental analysis was performed using SSMS and the samples were further analyzed for PCB materials.

The fuel flow rate to the boiler was determined using differential volume readings from a cumulative flow meter.

BOTTOM ASH

During each test period, three 1-liter samples of bottom ash were collected at regular intervals from the ash hopper and placed in a sample bucket. After the third sample was taken, the composited ash was thoroughly mixed and a 1-liter sample was extracted for analysis.

After size reduction, laboratory analysis of the bottom ash consisted of elemental characterization by SSMS and analysis for Hg by atomic absorption (AA). The bottom ash sample was also assayed for PAH and PCB materials.

A precise determination of the bottom ash generation rate was not possible because the ash accumulates in a hopper beneath the discharge end of the traveling grate and is removed only periodically through a pneumatic system. Also, the depth of ash in the hopper could not be determined, which precluded a calculation of the material volume based on the hopper dimensions.

Therefore, on the 2nd day of testing, the ash hopper was allowed to fill over a defined period of time. After the boiler was shut down, the hopper contents were transferred manually into 55 gal. drums. One of the drums was subsequently weighed and the result used as an average weight for all the drums. Thus, the bottom ash generation rate was estimated by calculating the total weight of material collected during that particular time period.

COLLECTOR INLET

Emission measurements of the flue gases leaving the boiler were made at the inlet to the mechanical collectors. The determinations consisted of particulate mass concentration, particle size distribution, and gas composition (O_2 and CO_2). Each of these measurements is briefly described next.

Particulate Mass Concentration

Three EPA Method 5 sampling runs were completed for the program. One run was made on the first day and two on the 2nd day of testing. Particulate concentrations were determined from both the front and back halves of the sampling train. After the weights of the collected particulate samples were determined, the filter samples were analyzed for elemental composition by SSMS.

A Fyrite gas analyzer and an orsat gas analyzer were used to measure the percentages of O_2 and CO_2 in the inlet gas stream. Triplicate readings were obtained during each particulate sampling run and the average value used in subsequent calculations.

Particle Size Distribution

A fine particle counting system, designed by MRI, was used to size the uncontrolled particulate emissions. Larger particles were counted by an optical counter, while the number of smaller particles was determined by a diffusion battery/condensation nuclei counter arrangement (see Appendix B for a description of this system). Because these devices can only accommodate a relatively small number of particulates per unit volume of sample, a dynamic dilution system was used to extract the sample from the inlet duct.

Particle counts were read directly from the counting instruments and were recorded for subsequent data reduction and analysis.

PRIMARY AND SECONDARY COLLECTOR ASH

Because the primary and secondary collector ash hoppers are emptied pneumatically, samples of the collected ashes could not be taken until the system was shut down at the end of the test day. UOP/Air Correction Division personnel, who were present at the site to monitor the collector operation and to make some of their own measurements, used a vacuum system to empty the collector hoppers into 208 liter (55 gal.) drums. One-liter samples of both the primary and secondary ash were obtained from the drums at the end of both test days. The ash samples were analyzed for elemental composition by SSMS and AA, and by GC/MS techniques for PCB and PAH materials.

The quantities of fly ash captured by the tandem mechanical collectors per unit time were estimated from measurements made by UOP personnel (who emptied the ash hoppers and weighed the collected material) and from calculations using the emission rates (kg/hr) measured by MRI at the inlet and outlet locations.

COLLECTOR OUTLET

The most extensive characterization of emissions was carried out on the postcollector flue gas exhaust. Each of the measured gas parameters is discussed below.

Particulate Mass Concentration

Simultaneous with the inlet sampling, three EPA Method 5 particulate samples were collected at the outlet of the mechanical collectors. The samples were subsequently weighed and the filters analyzed for elemental composition by SSMS and by AA for mercury.

Particle Size Distribution

The same particle counting system used at the collector inlet location was also used to determine the outlet size distribution. Three sampling runs were made at times adjacent to those of the inlet runs.

Orsat Analysis

Three grab samples of the flue gas were taken during each of the Method 5 particulate runs and were passed through an Orsat gas analyzer to measure the percentages of O_2 and CO_2 in the gas stream. These values were later used to calculate the molecular weight of the flue gases and the percentage of excess air used in the combustion process.

Opacity

Stack plume opacity was determined using EPA Method 9. Visual readings were taken for several hours each day to determine the average stack plume opacity. These periods of observation generally overlapped the times of the particulate tests.

Gas Composition

Continuous gas analyzers were used to monitor real-time concentrations of O_2, CO, NO_x, SO_2, and THC. A Teflon sample line transported the flue gas sample from the outlet duct to a field trailer which housed the monitoring equipment. There a manifold diverted a portion of the sample to each gas analyzer. Instrument responses were registered on strip chart recorders and transcribed to log sheets at 15-min intervals.

PCB and PAH

To collect PCB and PAH materials from the gas stream in both the particulate and gaseous phases, a special impinger/adsorption sampling train was used (see Appendix B for additional information). The measurement system consisted of a series of Greenburg-Smith impingers (containing water) with a solid adsorbent trap (Florisil adsorbent) placed between the third and fourth impingers. Samples were collected from 45 points in the duct cross-section, at a constant flow rate of approximately 1.7 liters/min (0.06 cfm). Two runs were obtained using this method, both on the first day of testing.

For laboratory analysis, the samples were extracted with an organic solvent and divided equally. GC/MS techniques were then used to analyze one sample portion for PCB compounds and the other for PAH materials.

SASS

The SASS is a device developed by the EPA for environmental assessment work (Level 1 environmental assessments). A brief explanation of the train and a schematic diagram of the system are included in Appendix D. The SASS train is designed to collect particulates in four size ranges, and to collect gaseous emissions simultaneously by adsorption on XAD-2 resin (for organic analysis) and by absorption in appropriate solutions (for vaporous trace metals).

One sampling run using the SASS, over nearly a 5-hr period, was completed on the final day of testing. Consistent with Level 1 protocol, the sample was taken isokinetically from a single point in the gas stream.

Analysis of the SASS components, as prescribed by the EPA's Level 1 environmental assessment procedure, is quite complex and includes analyses utilizing SSMS, AA, solvent extraction, infrared spectrophotometry (IR), low resolution mass spectrometry (LRMS), and liquid chromatography (LC). A detailed description of the analytical methodology employed for the SASS in this program is included in Appendix A.

CHEMICAL SPECIATION

In an effort to ascertain the chemical species of the most prevalent trace elements, selected particulate samples (based on SSMS results) were analyzed using electron spectroscopy for chemical analysis (ESCA). This technique, which is designed to determine the chemical composition of the surface layers of particles, is further discussed in the next section and in Appendix A.

SECTION 4

PRESENTATION AND DISCUSSION OF RESULTS

Boiler operating parameters and sampling/analytical results are discussed in this section. As presented in the previous section, each fuel input or effluent stream is examined separately, in general order of material flow through the system. The boiler operating conditions are presented first to provide a background for the discussions of the process streams.

BOILER OPERATING CONDITIONS

Operation of the No. 1 boiler during the MRI test program was monitored by Burlington Electric personnel. The boiler operator established and maintained firing conditions which produced the least visible stack plume. This was consistent with the plant's normal operating mode.

As described earlier in Section 2, the boiler fuel consisted of a combination of wood chips and No. 2 fuel oil. Wood is considered the primary fuel, but because of its inherently high moisture content (37 to 41%), the oil is added to ensure sufficient steam production for the electric turbine generator.

Fuel usage data for the 2 days of testing are summarized in Table 3. Input rates for the wood and oil fuels were obtained from the daily records maintained by Burlington Electric personnel. The values shown are averages of hourly fuel usage data.

The higher heating values shown in the table are the result of sample analyis by MRI. It should be pointed out that the heating values measured for the wood chips are probably slightly greater than comparative data compiled by other researchers for a similar type of wood. (5) This is most likely due to contamination from coal fines. In the plant's storage yard, the wood chip pile is adjacent to a coal storage area and the wood fuel invariably becomes "contaminated" with coal fines through wind erosion and the operation of the bulldozer which pushes the chips over to the feed conveyor pit. The heating values reported for this study, nevertheless, are representative of the actual fuel firing conditions at the plant during the time of the MRI test program. The values in Table 3 are not truly indicative, however, of the heat content

TABLE 3. SUMMARY OF FUEL INPUT DATA

	Wood chips		No. 2 fuel oil	
	7/24/78	7/25/78	7/24/78	7/25/78
Fuel feed rate				
Mg/hr (tons/hr)	7.92 (8.73)	8.92 (9.83)		
Liter/hr (gal/hr)			700 (185)	644 (170)
Higher heating value				
Btu/lb[a]	5,990	5,810	19,540	19,510
kJ/kg	13,720	13,510	45,450	45,390
Heat input rate				
10^6 Btu/hr	104.6	114.2	25.6	23.5
10^6 kJ/hr	110.4	120.5	27.0	24.8
Percent heat input contribution	80.3	82.9	19.7	17.1

[a] Heating values shown for the wood chip fuel are on an "as fired" basis. Also, these values may reflect the contribution of minute amounts of coal fines mixed in with the wood as a result of storage conditions.

of "clean" wood chips. By comparison, Burlington Electric has reported a Btu content of 5,240 Btu/lb for a sample of "clean" wood chips that was taken from the delivery truck near the time of the MRI test program.

Table 4 presents the average daily operating parameters for the No. 1 boiler. As shown by the data, boiler operation remained relatively steady, with only a small increase in the heat input rate (and consequently an increase in power output) on the 2nd day.

WOOD FUEL ANALYSIS

Results of the proximate and ultimate analyses of the wood fuel samples are shown in Table 5. The wood fuel's heating value was also determined and is presented on the basis of "as received," dry, and ash-free conditions. The total moisture values shown were obtained by combining the results of two moisture determinations. First, the samples were dried to a constant weight at slightly greater than ambient temperatures, yielding a "free" moisture value. After drying, the wood chips underwent size reduction for the subsequent proximate/ultimate analyses. The moisture values resulting from the proximate analysis are included in the total moisture data in Table 5.

TABLE 4. SUMMARY OF BOILER OPERATING PARAMETERS

	Test day	
	7/24/78	7/25/78
Steam flow		
kg/hr	42,200	40,400
lb/hr	93,000	89,000
Steam pressure		
kPa	5,520	5,585
psig	800	810
Steam temperature		
°C	427	440
°F	800	823
Furnace draft		
cm H_2O	+0.23	+0.91
in. H_2O	+0.09	+0.36
Economizer outlet draft		
cm H_2O	-10.2	-9.7
in. H_2O	-4.0	-3.8
Boiler heat input		
10^6 J/hr	137.4	145.3
10^6 Btu/hr	130.2	137.7
Generator power output		
MW	7.9	8.0

TABLE 5. ANALYSIS OF WOOD FUEL

Run No.	1	2	3	
Date	7/24/78	7/25/78	7/25/78	Average
Total moisture (%)	37.01	39.02	41.23	39.09
Proximate analysis (%)[a]				
Ash	5.59	3.80	3.49	4.29
Volatile matter	66.68	70.12	73.35	70.05
Fixed carbon	27.73	26.08	23.16	25.66
Total	100.00	100.00	100.00	100.00
Ultimate analysis (%)[a]				
Ash	5.59	3.80	3.49	4.29
Carbon	53.31	54.11	51.74	53.05
Hydrogen	5.76	5.78	5.96	5.83
Oxygen	34.60	35.74	38.38	36.24
Sulfur	0.44	0.35	0.25	0.35
Nitrogen	0.27	0.26	0.12	0.22
Total	99.97	100.04	99.94	99.98
Heat of combustion (kJ/kg)				
As received	13,930	13,670	13,360	13,650
Dry basis	21,840	22,080	22,210	22,040
Dry, ash-free basis	23,130	22,950	23,010	23,030

[a] Dry basis.

As mentioned previously, coal particles had unavoidably been mixed in with the wood chips through storage and handling, so that the wood fuel characteristics presented in Table 5 reflect this condition. Percentages of ash and sulfur, in particular, are higher than typical published values for wood. Furthermore, Burlington Electric Department has reported results from analysis of a wood sample taken directly from a delivery van in September 1978. This sample was representative of clean, fresh wood chips. The resulting composition is shown in Table 6.

TABLE 6. WOOD FUEL COMPOSITION REPORTED BY BURLINGTON ELECTRIC

	As received (%)	Dry (%)
Total moisture	38.29	-
Volatile matter	48.33	78.32
Fixed carbon	12.14	19.67
Ash	1.24	2.01
Sulfur	0.04	0.06
Heating value (Btu/lb)	5,240	8,491

In contrast to the ash content measured by MRI (4.29%), the Burlington Electric data show a value of 2.01% (on a dry basis). Likewise, the 0.06% sulfur reported in Burlington Electric's sample, was much lower than the 0.35% average resulting from the MRI analyses. Periodic wood sample analysis has never shown sulfur contents in excess of 0.1% according to plant personnel. These differences are too large to be attributed to the natural variations in wood composition alone, and therefore coal infiltration is probably the major cause for the discrepancy.

Elemental composition of the wood fuel was also determined, using SSMS, and the results are displayed in Table 7. With the exception of many common elements (i.e., Fe, Mn, Ti, Ca, K, S, P, Si, and Mg which were detected at levels > 100 μg/g), the data show very low concentrations ($\leq$ 1 μg/g) of most elements. Several notable exceptions include Ba, Sr, As, Zn, Cr, Cl, and Fl, whose concentrations were in the range of 25 to 100 μg/g.

FUEL OIL ANALYSIS

Results of the ultimate analysis of the two No. 2 fuel oil samples are shown in Table 8. The amount of ash in the oil was negligible (< 0.001%). Sulfur content averaged 0.35%. The heat of combustion of the fuel oil was determined and averaged 45,400 kJ/kg (19,520 Btu/lb or 138,100 Btu/gal) for the two samples.

TABLE 7. ELEMENTAL ANALYSIS OF WOOD BY SSMS

Element	Concentration (µg/g) Run 1a/	Concentration (µg/g) Run 1 Duplicatea/	Concentration (µg/g) Run 2a/	Concentration (µg/g) Range	Element	Concentration (µg/g) Run 1a/	Concentration (µg/g) Run 1 Duplicatea/	Concentration (µg/g) Run 2a/	Concentration (µg/g) Range
Uranium	0.4	≤ 0.2	0.2	≤ 0.2 - 0.4	Ruthenium	-	-	-	< 0.02
Thorium	1	≤ 0.2	0.4	≤ 0.2 - 1	Molybdenum	0.7	0.3	1	0.3 - 1
Bismuth	0.03	-	0.1	< 0.02 - 0.1	Niobium	2	0.3	1	0.3 - 2
Lead	4	2	4b/	2 - 4	Zirconium	7	3	10	3 - 10
Thallium	0.4	-	0.07	< 0.02 - 0.4	Yttrium	2	0.6	3	0.6 - 3
Mercury	NR	NR	0.20c/	-	Strontium	57	15	62	15 - 62
Gold	-	-	-	< 0.02	Rubidium	6	16	6	6 - 16
Platinum	-	-	-	< 0.02	Bromine	0.6	0.8	2	0.6 - 2
Iridium	-	-	-	< 0.02	Selenium	0.9	0.3	0.9	0.3 - 0.9
Osmium	-	-	-	< 0.02	Arsenic	7	48	5	5 - 48
Rhenium	-	-	-	< 0.02	Germanium	0.8	0.2	0.6	0.2 - 0.8
Tungsten	0.2	-	0.1	< 0.02 - 0.2	Gallium	5	15	5	5 - 15
Tantalum	≤ 0.06	-	-	≤ 0.06	Zinc	43	35	56	35 - 56
Hafnium	0.3	-	0.2	< 0.02 - 0.3	Copper	14	25	7	7 - 25
Lutetium	0.04	-	0.02	< 0.02 - 0.04	Nickel	29	10	18	10 - 29
Ytterbium	0.2	-	0.1	< 0.02 - 0.2	Cobalt	49	0.8	1	0.8 - 49
Thulium	0.02	-	0.02	≤ 0.02	Iron	MC	MC	MC	> 100
Erbium	0.1	-	0.07	< 0.02 - 0.1	Manganese	MC	MC	MC	> 100
Holmium	0.2	-	0.1	< 0.02 - 0.2	Chromium	12	21	MC	12 - > 100
Dysprosium	0.3	-	0.2	< 0.02 - 0.3	Vanadium	16	2	19	2 - 19
Terbium	0.1	-	0.09	< 0.02 - 0.1	Titanium	MC	MC	MC	> 100
Gadolinium	0.4	-	0.2	< 0.02 - 0.4	Scandium	0.9	0.3	1	0.3 - 1
Europium	0.09	0.03	0.1	0.03 - 0.1	Calcium	MC	MC	MC	> 100
Samarium	0.8	0.1	0.4	0.1 - 0.8	Potassium	MC	MC	MC	> 100
Neodymium	2	0.1	0.5	0.1 - 2	Chlorine	22	29	27	22 - 29
Praseodymium	0.8	0.05	0.3	0.05 - 0.8	Sulfur	MC	MC	MC	> 100
Cerium	4	0.4	1	0.4 - 1	Phosphorus	MC	MC	MC	> 100
Lanthanum	4	0.6	1	0.6 - 1	Silicon	MC	MC	MC	> 100
Barium	68	25	82b/	25 - 82	Aluminum	> 16	> 23	> 19	> 16
Cesium	0.3	0.3	0.07	0.07 - 0.3	Magnesium	MC	MC	MC	> 100
Iodine	0.2	0.1	0.07	0.07 - 0.2	Sodium	> 40	> 60	> 50	> 40
Tellurium	-	-	-	< 0.02	Fluorine	≃ 74	≃ 80	MC	74 - > 100
Antimony	5	0.4	0.7b/	0.7 - 5	Oxygen	NR	NR	NR	-
Tin	0.6	0.8	2b/	0.6 - 2	Nitrogen	NR	NR	NR	-
Indium	STD	STD	STD	-	Carbon	NR	NR	NR	-
Cadmium	0.1	-	0.3	< 0.02 - 0.3	Boron	1	17	0.8	0.8 - 17
Silver	0.2	0.1	0.08	0.08 - 0.2	Beryllium	0.2	0.01	0.08	0.01 - 0.2
Palladium	-	-	-	< 0.02	Lithium	3	0.8	1	0.8 - 3
Rhodium	-	-	-	< 0.02					

Note: NR = not reported.
STD = internal standard.
MC = major component, > 100 µg/g.

a/ Elements not detected < 0.02 µg/g.

b/ Heterogeneous.

c/ Flameless atomic absorption.

TABLE 8. ANALYSIS OF NO. 2 FUEL OIL

Run No. Date	1 7/24/78	2 and 3 7/25/78	Average
Ultimate analysis (%)			
Ash	< 0.001	< 0.001	< 0.001
Carbon	84.94	81.84	83.39
Hydrogen	12.93	11.38	12.16
Oxygen	1.79	6.41	4.10
Sulfur	0.33	0.36	0.35
Nitrogen	0.01	0.01	0.01
Total	100.00	100.00	100.01
Heat of combustion (kJ/kg)	45,450	45,360	45,400

As with the wood fuel, the fuel oil was analyzed for elemental composition. All resulting concentrations, which are shown in Table 9, appear very low. Many elements could not be detected at a lower limit of 0.06 μg/g. The only elements observed at concentrations greater than 10 μg/g were Fe, Ca, S, Si, and F. The highest single concentration reported was for iron at 25 μg/g.

BOTTOM ASH

The bottom ash generation rate, resulting from combustion of wood chips, could only be estimated on the 2nd day of testing. As described in the previous section, the total quantity of ash produced during the 12 hr of boiler operation was measured by weighing 55 gal. drums which contained the removed material. By this method, a total ash weight of about 1,090 kg was obtained, which corresponds to an ash generation rate of approximately 90.7 kg/hr. This amount is just slightly over 1% of the wood chips feed rate (8.9 Mg/hr) on a wet weight basis, or about 1.7% on a dry weight basis.

Elemental analysis of the bottom ash using SSMS was conducted and the data are presented in Table 10. Almost without exception, the elemental concentrations were much greater in the ash relative to the wood and oil fuels. The major elements (Fe, Mn, Ti, Ca, K, S, P, Si, Al, Mg, and Na) were present at levels greater than 1,000 μg/g. Other elements (Ba, Zr, Si, and Li, in particular) showed substantial increases in concentrations when compared to their levels in the fuels. However, several of the more volatile elements, such as Sb, As, and Se, exhibited very little or no increase in concentration, as expected.

TABLE 9. ELEMENTAL ANALYSIS OF FUEL OIL BY SSMS

Element	Concentration (µg/g) Run 1[a]	Run 1 Duplicate[b]	Run 2[c]	Range	Element	Concentration (µg/g) Run 1[a]	Run 1 Duplicate[b]	Run 2[c]	Range
Uranium	-	-	-	-	Ruthenium	-	-	-	-
Thorium	-	-	-	-	Molybdenum	0.1	< 0.05	< 0.06	< 0.1
Bismuth	-	-	-	-	Niobium	-	-	-	-
Lead	≤ 0.2	0.4	≤ 0.3	≤ 0.2 - 0.4	Zirconium	-	-	-	-
Thallium	-	-	-	-	Yttrium	-	-	-	-
Mercury	NR	NR	0.28[d]	-	Strontium	< 0.04	0.04	< 0.06	< 0.06
Gold	-	-	-	-	Rubidium	-	-	-	-
Platinum	-	-	-	-	Bromine	< 0.04	≤ 0.1	< 0.06	< 0.1
Iridium	-	-	-	-	Selenium	-	-	-	-
Osmium	-	-	-	-	Arsenic	< 0.04	0.1	< 0.06	< 0.04 - 0.1
Rhenium	-	-	-	-	Germanium	-	-	-	-
Tungsten	-	-	-	-	Gallium	< 0.04	≤ 0.07	< 0.06	≤ 0.07
Tantalum	-	-	-	-	Zinc	0.1	0.2	0.4	0.1 - 0.4
Hafnium	-	-	-	-	Copper	0.3	0.3	0.4	0.3 - 0.4
Lutetium	-	-	-	-	Nickel	0.2	2	2[e]	0.2 - 2
Ytterbium	-	-	-	-	Cobalt	≤ 0.02	0.02	0.01	≤ 0.02
Thulium	-	-	-	-	Iron	2	25	3	2 - 25
Erbium	-	-	-	-	Manganese	0.02	0.3	0.07	0.02 - 0.3
Holmium	-	-	-	-	Chromium	≤ 0.1	0.8	0.2	≤ 0.1 - 0.8
Dysprosium	-	-	-	-	Vanadium	0.02	0.3	0.1	0.02 - 0.3
Terbium	-	-	-	-	Titanium	0.2	≤ 0.6	≤ 0.6	≤ 0.6
Gadolinium	-	-	-	-	Scandium	≤ 0.007	≤ 0.03	≤ 0.08	≤ 0.08
Europium	-	-	-	-	Calcium	12	13	17	12 - 17
Samarium	-	-	-	-	Potassium	2	1	2	1 - 2
Neodymium	-	-	-	-	Chlorine	0.3	0.2	5[e]	0.2 - 5
Praseodymium	-	-	-	-	Sulfur	3	11	4	3 - 11
Cerium	-	-	-	-	Phosphorus	2	0.6	3	0.6 - 3
Lanthanum	-	-	-	-	Silicon	7	12	16	7 - 16
Barium	≤ 0.1	0.6	≤ 0.2	≤ 0.1 - 0.6	Aluminum	0.5	0.3	7[e]	0.3 - 7
Cesium	-	-	-	-	Magnesium	2	5	3	2 - 5
Iodine	-	-	-	-	Sodium	2	3	3	2 - 3
Tellurium	-	-	-	-	Fluorine	≃ 7	≃ 2	≃ 16	2 - 16
Antimony	< 0.04	≤ 0.09	-	< 0.09	Oxygen	NR	NR	NR	-
Tin	-	-	-	-	Nitrogen	NR	NR	NR	-
Indium	STD	STD	STD	-	Carbon	NR	NR	NR	-
Cadmium	-	-	-	-	Boron	≤ 0.09	≤ 0.1	≤ 0.2	≤ 0.2
Silver	< 0.04	0.09	-	< 0.04 - 0.09	Beryllium	-	-	-	-
Palladium	-	-	-	-	Lithium	0.01	0.01	0.02	0.01 - 0.02
Rhodium	-	-	-	-					

Note: NR = not reported.
STD = internal standard.

[a] All elements not detected < 0.04 µg/g.

[b] All elements not detected < 0.05 µg/g.

[c] All elements not detected < 0.06 µg/g.

[d] Flameless atomic absorption.

[e] Heterogeneous signal.

TABLE 10. ELEMENTAL ANALYSIS OF BOTTOM ASH BY SSMS

	Concentration (μg/g)					Concentration (μg/g)			
Element	Run 1	Run 1 Duplicate	Run 2	Range	Element	Run 1	Run 1 Duplicate	Run 2	Range
Uranium	9	6	4	4 - 9	Ruthenium	-	-	-	< 0.2
Thorium	16	11	8	8 - 16	Molybdenum	14	7	6	6 - 14
Bismuth	-	-	-	< 0.2	Niobium	65	30	46	30 - 65
Lead	8	4	4	4 - 8	Zirconium	MC b/	340	190	190-> 1,000
Thallium	-	≤ 0.7	-	< 0.7	Yttrium	140	69	73	69 - 140
Mercury	NR	NR	0.09 a/	0.09	Strontium	MC	940	800	800-> 1,000
Gold	-	-	-	< 0.2	Rubidium	110	90	87	87 - 110
Platinum	-	-	-	< 0.2	Bromine	1	2	2	1 - 2
Iridium	-	-	-	< 0.2	Selenium	2	3	1	1 - 3
Osmium	-	-	-	< 0.2	Arsenic	16	11	19	11 - 19
Rhenium	-	-	-	< 0.2	Germanium	4	6	2	2 - 6
Tungsten	2	3	≤ 1	≤ 1 - 3	Gallium	50	35	59	35 - 59
Tantalum	-	-	-	< 0.2	Zinc	55	17	150	17 - 150
Hafnium	4	3	2	2 - 4	Copper	100	88	67	67 - 100
Lutetium	0.4	0.3	-	< 0.2 - 0.4	Nickel	100	48	93	48 - 100
Ytterbium	2	2	-	< 0.2 - 2	Cobalt	58	27	17	17 - 58
Thulium	0.3	0.4	0.2	0.2 - 0.4	Iron	MC	MC	MC	> 1,000
Erbium	1	2	0.9	0.9 - 2	Manganese	MC	530	MC	> 1,000
Holmium	2	2	1	1 - 2	Chromium	480	240	210	210 - 480
Dysprosium	4	3	2	2 - 4	Vanadium	360	160	230	160 - 360
Terbium	1	0.8	1	0.8 - 1	Titanium	MC	MC	MC	> 1,000
Gadolinium	3	2	3	2 - 3	Scandium	110 b/	20	13	13 - 110
Europium	1	1	1	1	Calcium	MC	MC	MC	> 1,000
Samarium	10	11	9	9 - 11	Potassium	MC	MC	MC	> 1,000
Neodymium	28	12	20	12 - 28	Chlorine	21	33	50	21 - 50
Praseodymium	13	6	9	6 - 13	Sulfur	MC	MC	MC	> 1,000
Cerium	88	68	58	58 - 88	Phosphorus	MC	MC	MC	> 1,000
Lanthanum	87	27	58	27 - 87	Silicon	MC	MC	MC	> 1,000
Barium	MC	MC	MC	> 1,000	Alumium	MC	MC	MC	> 1,000
Cesium	6	3	7	3 - 7	Magnesium	MC	MC	MC	> 1,000
Iodine	-	-	-	< 0.2	Sodium	MC	MC	MC	> 1,000
Tellurium	-	-	-	< 0.2	Fluorine	≃ 89	≃ 180	≃ 200	89 - 200
Antimony	4	2	1	1 - 4	Oxygen	NR	NR	NR	-
Tin	2	2	2	2	Nitrogen	NR	NR	NR	-
Indium	STD	STD	STD	-	Carbon	NR	NR	NR	-
Cadmium	0.6	≤ 0.4	≤ 0.4	≤ 0.4 - 0.6	Boron	71	62	84	62 - 84
Silver	0.3	≤ 0.2	0.4	≤ 0.2 - 0.4	Beryllium	8	3	9	3 - 9
Palladium	-	-	-	< 0.2	Lithium	530	920	320	320 - 920
Rhodium	-	-	-	< 0.2					

Note: NR = not reported.
MC = major component, > 1,000 μg/g.
STD = internal standard
Dashes indicate not detected (< 0.2 μg/g)

a/ Flameless atomic absorption.

b/ Heterogeneous.

Bottom ash samples were also analyzed for PCB using electron capture gas chromatography (EC/GC) and gas chromatography-mass spectrometry (GC/MS). No PCB signals were obtained above the detection limit of 0.05 μg/g.

Analysis of the ash samples for PAH materials resulted in some positive confirmations, as shown in Table 11. However, only phenanthrene could be verified as being present at levels exceeding the limit of detection. The signals observed for fluoranthrene, pyrene, 1,2-benzanthracene, and benzo[a]pyrene could not be positively confirmed due to the absence of observable confirmatory ion fragments.

TABLE 11. ANALYSIS OF BOTTOM ASH FOR PAH BY GC/MS

Compound	Detection limit[a] (μg/g)	Run 1 (μg/g)	Run 1 duplicate (μg/g)	Run 2 (μg/g)
Acenaphthylene	0.56[b]	-[d]	-	-
Fluorene	0.54[b]	-	-	-
Phenanthrene	0.24[b]	0.56	0.40	1.7
Anthracene	0.15[b]	-	-	-
Fluoranthene	0.17[b]	< 0.17[e]	< 0.17[e]	< 0.17[f]
Pyrene	0.16[b]	< 0.16[e]	< 0.16[e]	< 0.16[f]
Chrysene	0.50[c]	-	-	-
1,2-Benzanthracene	0.47[b]	-	< 0.47[e]	< 0.47[e]
Benzo[a]pyrene	6.7[b]	-	-	< 6.7[e]
Perylene	0.56[c]	-	-	-
Indeno[1,2,3-c,d]pyrene	1.5[c]	-	-	-
1,2,5,6-Dibenzanthracene	2.2[c]	-	-	-
1,12-Benzoperylene	1.4[c]	-	-	-

[a] Assuming a 20 g sample weight and a 1,000 count minimum signal.

[b] Based on response factors determined using 1 μl of a 1 ng/μl standard.

[c] Based on response factors determined using 1 μl of a 5 ng/μl standard.

[d] Blank values indicate no observable signal.

[e] Signals were observed which corresponded to quantities of material less than the detection limit and which could not be verified by GC/MS.

[f] Unconfirmed by GC/MS due to coelution of interfering materials.

UNCONTROLLED AIR EMISSIONS (COLLECTOR INLET)

Air emissions from the boiler were sampled and analyzed, at the collector inlet, to determine pollutant constituents. Measurements included particulate mass concentration, elemental composition of the mass samples, gas composition (CO_2 and O_2) and particle size distribution. Each of these aspects is discussed below.

Particulate Mass Concentration

The concentration of particulate in the uncontrolled gas stream was measured by EPA Method 5. Three samples were collected and analyzed to yield the data shown in Table 12. The average particulate concentration was 2.96 g/dscm (1.30 gr/dscf). On a heat input basis, the particular emission rate averaged 1.47 g/MJ (3.43 lb/10^6 Btu).

TABLE 12. UNCONTROLLED AIR EMISSIONS

Constituent	Run No.			Average
	1	2	3	
Particulate[a]				
g/dscm	3.32	2.62	2.94	2.96
gr/dscf	1.45	1.15	1.29	1.30
kg/hr	241	183	205	210
lb/hr	531	403	451	462
g/MJ heat input	1.75	1.26	1.41	1.47
lb/10^6 Btu	4.08	2.93	3.28	3.43
Percent CO_2	7.7	11.0	6.0	8.2
Percent O_2	12.5	10.5	14.0	12.3
Elemental composition	13 (see Table 13)			
Particle size distribution	15-17 (see Tables 15-17)			

[a] Results shown are for front half of the Method 5 train only.

The emission values shown in Table 12 represent particulate collected by the front half of the EPA Method 5 train since it is this portion that is normally reported and compared to emission regulations. An additional 0.09 g/dscm (average) was measured in the back half of the sampling train. These condensible emissions represent only about 2.5% of the total particulate sample. A complete summary of the particulate emission results is presented later in this report with the discussion of outlet emissions.

Gas Composition

Oxygen and carbon dioxide concentrations in the boiler exhaust gases averaged 12.3 and 8.2%, respectively. Oxygen contents ranged from 10.5 to 14.0%, while the CO_2 content varied between 6.0 and 11.0%. Boiler excess air values, calculated from these readings, ranged from 103 to 197% and indicated some fluctuation in boiler operation. The lowest and highest excess air values were observed during the second and third particulate runs, respectively, which were both conducted on the 2nd day of the testing. For the first particulate sampling run on the first day, the calculated excess air usage was 146%.

Particulate Elemental Composition

Portions of the Method 5 particulate filter samples were analyzed by SSMS to determine the elemental composition of the uncontrolled particulate emissions. Table 13 presents the resulting data.

Concentrations of many of the most common elements (Ca, K, Cl, S, Si, Al, Mg, Na, F, and B) could not be quantified because background levels of these elements from the glass fiber filter matrix exceeded the SSMS analytical range.

Of the remaining elements, the highest concentrations (> 100 µg/g) were observed for Pb, Ba, Sr, As, Ga, Zn, Cu, Fe, Mn, Ti, and P. The emission rates for these elements are shown in Table 14a (air concentrations) and Table 14b (emission factors).

Particle Size Distribution

The size distribution of uncontrolled particulate emissions was measured using an optical/diffusional particle counting system constructed by MRI. This sampling method was selected in place of the more traditional cascade impactor technique because it was anticipated that a majority of the emitted particulate would be in the submicron size range. The optical/diffusional system is capable of providing data in size regions well below the lower limits of currently used impactors, while still operating comparably in the upper ranges. By diffusion methods, particles can be sized down to 0.002 µm, whereas cascade impactors can only yield data to about 0.1 µm.

TABLE 13. ELEMENTAL ANALYSIS OF INLET METHOD 5 FILTER PARTICULATE BY SSMS

Element	Concentration (μg/g) Run 1[a]	Run 1 Duplicate[b]	Run 2[c]	Run 3[d]	Range	Element	Concentration (μg/g) Run 1[a]	Run 1 Duplicate[b]	Run 2[c]	Run 3[d]	Range
Uranium	-	-	1	-	< 0.03 - 1	Ruthenium	-	-	-	-	< 0.07
Thorium	-	-	1	-	< 0.03 - 1	Molybdenum	10	3[e]	10	20	3 - 20
Bismuth	≤ 0.03[e]	≤ 0.05[e]	≤ 0.04[e]	≤ 0.07[e]	≤ 0.07	Niobium	5	2	8	7	2 - 8
Lead	200	200	200	100	100 - 200	Zirconium	20	20	40	70	20 - 70
Thallium	5	5	8	0.3[e]	0.3 - 8	Yttrium	10	5	20	30	5 - 30
Mercury	31.0[g]	30.6[g]	100[g]	55.1[g]	30.6-100	Strontium	80	300	300	300	80 - 300
Gold	-	-	-	-	< 0.07	Rubidium	20	40	40	10	10 - 40
Platinum	-	-	-	-	< 0.07	Bromine	50	40	80	70	40 - 80
Iridium	-	-	-	-	< 0.07	Selenium	20	20	40	40	20 - 40
Osmium	-	-	-	-	< 0.07	Arsenic	200	500	≥ 400[f]	100	100 - > 400
Rhenium	-	-	-	-	< 0.07	Germanium	10	10	30	30	10 - 30
Tungsten	-	-	0.08[e]	-	< 0.03 - 0.08	Gallium	50	50	300	50	50 - 300
Tantalum	-	-	-	-	< 0.07	Zinc	≥ 300[f]	≥ 500[f]	≥ 400[f]	≥ 700[f]	≥ 300
Hafnium	-	-	0.1[e]	-	< 0.03 - 0.1	Copper	80	200	100	200	80 - 200
Lutetium	-	-	≤ 0.04[e]	-	< 0.07	Nickel	50	40	40	70	40 - 70
Ytterbium	-	-	0.1[e]	-	< 0.03 - 0.1	Cobalt	≤ 0.03[e]	≤ 0.05[e]	≤ 0.04[e]	≤ 0.04[e]	≤ 0.05
Thulium	-	-	≤ 0.04[e]	-	< 0.07	Iron	≥ 300[f]	≥ 500[f]	≥ 400[f]	≥ 700[f]	≥ 300
Erbium	-	-	0.04[e]	-	< 0.07	Manganese	200	≥ 200	≥ 200	400	≥ 200
Holmium	-	-	0.1[e]	-	< 0.03 - 0.1	Chromium	≤ 0.03[e]	≤ 0.05[e]	≤ 0.04[e]	≤ 0.07[e]	≤ 0.07
Dysprosium	-	-	0.2[e]	-	< 0.03 - 0.2	Vanadium	10	40	30	50	10 - 50
Terbium	-	-	≤ 0.04[e]	-	< 0.07	Titanium	≥ 300[f]	≥ 500[f]	≥ 600[f]	≥ 700[f]	≥ 300
Gadolinium	-	-	-	-	< 0.07	Scandium	1	2	4	7	1 - 7
Europium	-	-	≤ 0.04[e]	-	< 0.07	Calcium	B	B	B	B	-
Samarium	-	-	2	-	< 0.03 - 2	Potassium	B	B	B	B	-
Neodymium	0.5	2	3	2	0.5 - 3	Chlorine	B	B	B	B	-
Praseodymium	1	0.6[e]	2	0.3	0.3 - 2	Sulfur	B	B	B	B	-
Cerium	20	20	20	50	20 - 50	Phosphorus	≥ 300[f]	≥ 500[f]	≥ 400[f]	≥ 700[f]	≥ 300
Lanthanum	20	20	20	30	20 - 30	Silicon	B	B	B	B	-
Barium	300	200	400	200	200 - 400	Aluminum	B	B	B	B	-
Cesium	0.05	0.05[e]	2	0.3	0.05 - 2	Magnesium	B	B	B	B	-
Iodine	8	10	8	10	8 - 10	Sodium	B	B	B	B	-
Tellurium	-	-	≤ 0.04[e]	-	< 0.07	Fluorine	B	B	B	B	-
Antimony	8	4	10	10	4 - 10	Oxygen	NR	NR	NR	NR	-
Tin	10	10	10	30	10 - 30	Nitrogen	NR	NR	NR	NR	-
Indium	STD	STD	STD	STD	-	Carbon	NR	NR	NR	NR	-
Cadmium	3	4	0.2	0.5	0.2 - 4	Boron	B	B	B	B	-
Silver	2	2	2	0.2[e]	0.2 - 2	Beryllium	≤ 0.03[e]	0.09[e]	0.6[e]	≤ 0.07[e]	≤ 0.01 - 0.6
Palladium	-	-	-	-	< 0.07	Lithium	2	50	20	2	2 - 50
Rhodium	-	-	-	-	< 0.07						

Note: B = background level exceeds analytical range.
NR = not reported.
STD = internal standard.

[a] Detection limit = 0.03 μg/g.

[b] Detection limit = 0.05 μg/g.

[c] Detection limit = 0.04 μg/g.

[d] Detection limit = 0.07 μg/g.

[e] Corrected for background levels > 20% of the sample value.

[f] Major component.

[g] Flameless atomic absorption.

TABLE 14a. AIR EMISSION CONCENTRATIONS FOR SELECTED ELEMENTS IN UNCONTROLLED PARTICULATE

Element	Concentration (μg/dscm) Run 1	Run 2	Run 3	Range
Lead	38	34	11	11-38
Barium	57	69	22	22-69
Strontium	15	51	34	15-51
Arsenic	38	≥ 69	11	11-≥ 69
Gallium	10	51	6	6-51
Zinc	≥ 57	≥ 69	≥ 79	≥ 57
Copper	15	17	22	15-22
Iron	≥ 57	≥ 69	≥ 79	≥ 57
Manganese	38	≥ 34	45	≥ 34
Titanium	≥ 57	≥ 69	≥ 79	≥ 57
Phosphorus	≥ 57	≥ 69	≥ 79	≥ 57
Mercury	5.9	17	6.2	6-17

TABLE 14b. AIR EMISSION FACTORS FOR SELECTED ELEMENTS IN UNCONTROLLED PARTICULATE

Element	Emission factor (mg/MJ) Run 1	Run 2	Run 3	Average
Lead	20	16	5.3	14
Barium	30	33	11	25
Strontium	7.9	25	16	16
Arsenic	20	≥ 33	5.3	≥ 19
Gallium	5.3	25	2.9	11
Zinc	≥ 30	≥ 33	≥ 38	≥ 34
Copper	7.9	8.2	11	9
Iron	≥ 30	≥ 33	≥ 38	≥ 34
Manganese	20	≥ 16	22	19
Titanium	≥ 30	≥ 33	≥ 38	≥ 34
Phosphorus	≥ 30	≥ 33	≥ 38	≥ 34
Mercury	3.1	8.2	3.0	4.8

The original intention of the MRI sampling team was to use the particle counting system in its unrestricted mode to obtain data over the full particle size spectrum. However, during the first sampling run it was discovered that the larger particles in the air stream were causing plugging in the dynamic dilution/conditioning system. To alleviate this problem a cyclone was added to the front of the system (see Appendix B). Since the cyclone has a particle diameter cutoff of 2.65 µm, those particles larger than 2.65 µm were captured and prevented from entering the particle counting system. Thus, this portion of the particle size spectrum is not included in the reported data.

The data obtained from the optical/diffusional system are presented in Tables 15 through 17. Particles in the range of 0.3 to 2.6 µm were counted by the optical system which segregated the particle counts into six discrete ranges, as shown in Table 15. These data indicate a progressive increase in the number of particles observed as the particle size decreases.

The diffusion battery/condensation nuclei counter data shown in Tables 16 and 17 represent counts of particles in the range of about 0.005 to 0.10 µm. Values in Table 16 are the measurement output of the nuclei counter as the sample stream was passed through the cumulative stages of the diffusion battery. Fractional penetration data were calculated from the corresponding particle concentrations. Using this information and a graphical stripping technique, the size distribution data presented in Table 17 was developed. The size ranges listed vary for each run because of limitations imposed by the graphical data reduction method. An average of 47% of the particles measured by the condensation nuclei counter were larger than 0.040 µm, while another 40% were between 0.025 and 0.040 µm in diameter. Only 1 to 2% of the measured particles were less than 0.02 µm.

TABLE 15. INLET PARTICLE SIZE DISTRIBUTION BY NUMBER AS MONITORED BY THE OPTICAL COUNTER

	Particulate concentration (10^6 particles/cu m)a/			
Size range (µm)	Run 1	Run 2	Run 3	Average
Channel 6 (1.5-2.6)	59.8	10.8	13.1	27.9
Channel 5 (1.2-1.5)	98.0	22.2	25.9	48.7
Channel 4 (0.9-1.2)	200	50.8	58.5	103
Channel 3 (0.7-0.9)	354	105	115	191
Channel 2 (0.5-0.7)	746	250	239	419
Channel 1 (0.3-0.5)	2,250	943	913	1,370

a/ At standard conditions (29.92 in. Hg and 68°F).

TABLE 16. INLET PARTICLE COUNTS BY SIZE AS MONITORED BY THE DIFFUSION BATTERY/CONDENSATION NUCLEI COUNTER

Diffusion battery port No.	Particulate concentration (10^6 particles/cu m)[a/]				Fractional penetration			
	Run 1	Run 2	Run 3	Average	Run 1	Run 2	Run 3	Average
0	1,795	1,520	1,368	1,561	1.000	1.000	1.000	1.000
1	1,795	1,094	1,216	1,368	1.000	0.720	0.889	0.876
2	1,795	1,016	1,216	1,342	1.000	0.668	0.889	0.860
3	1,346	760	760	955	0.750	0.500	0.556	0.612
4	898	577	380	452	0.500	0.380	0.278	0.290
5	448	182	152	261	0.249	0.120	0.111	0.167
6	216	106	76	133	0.120	0.070	0.056	0.085
7	107	27	37	57	0.060	0.018	0.027	0.037
8	45	15	15	25	0.025	0.010	0.011	0.016
9	20	12	10	14	0.011	0.008	0.007	0.009
10	13	7	6	7	0.007	0.005	0.004	0.006

[a/] At standard conditions (29.92 in. Hg and 68 F).

TABLE 17. INLET PARTICLE SIZE DISTRIBUTION RESULTING FROM DIFFUSION BATTERY PENETRATION DATA

Run No.	Size range (μm)	No. of particles[a] (10^6 particles/cu m)	Percent of particles in stated size range
1	> 0.045	718	40.0
	0.030-0.045	790	44.0
	0.025-0.030	269	15.0
	< 0.025	18	1.0
2	> 0.055	155	10.2
	0.025-0.055	784	51.6
	0.020-0.025	456	30.0
	0.010-0.020	58	3.8
	< 0.010	67	4.4
3	> 0.035	711	52.0
	0.020-0.035	595	43.5
	< 0.020	62	4.5
Average	> 0.040	734	47.0
	0.025-0.040	624	40.0
	0.020-0.025	184	11.8
	< 0.020	19	1.2

[a] At standard conditions.

Graphical representations of the optical and diffusional sizing results are presented in Figures 4 through 6. A definite data gap is evident between the lower limit of the optical range and the upper limit of the diffusional range. No extrapolation of the curves was made because of the difficulty in accurately predicting the changing curve slope in the area of the disfunction.

PRIMARY AND SECONDARY COLLECTOR ASH

Samples of collected fly ash were taken from both the primary and secondary collector hoppers each day. Analyses were then conducted to determine elemental composition and concentrations of PCB and PAH compounds.

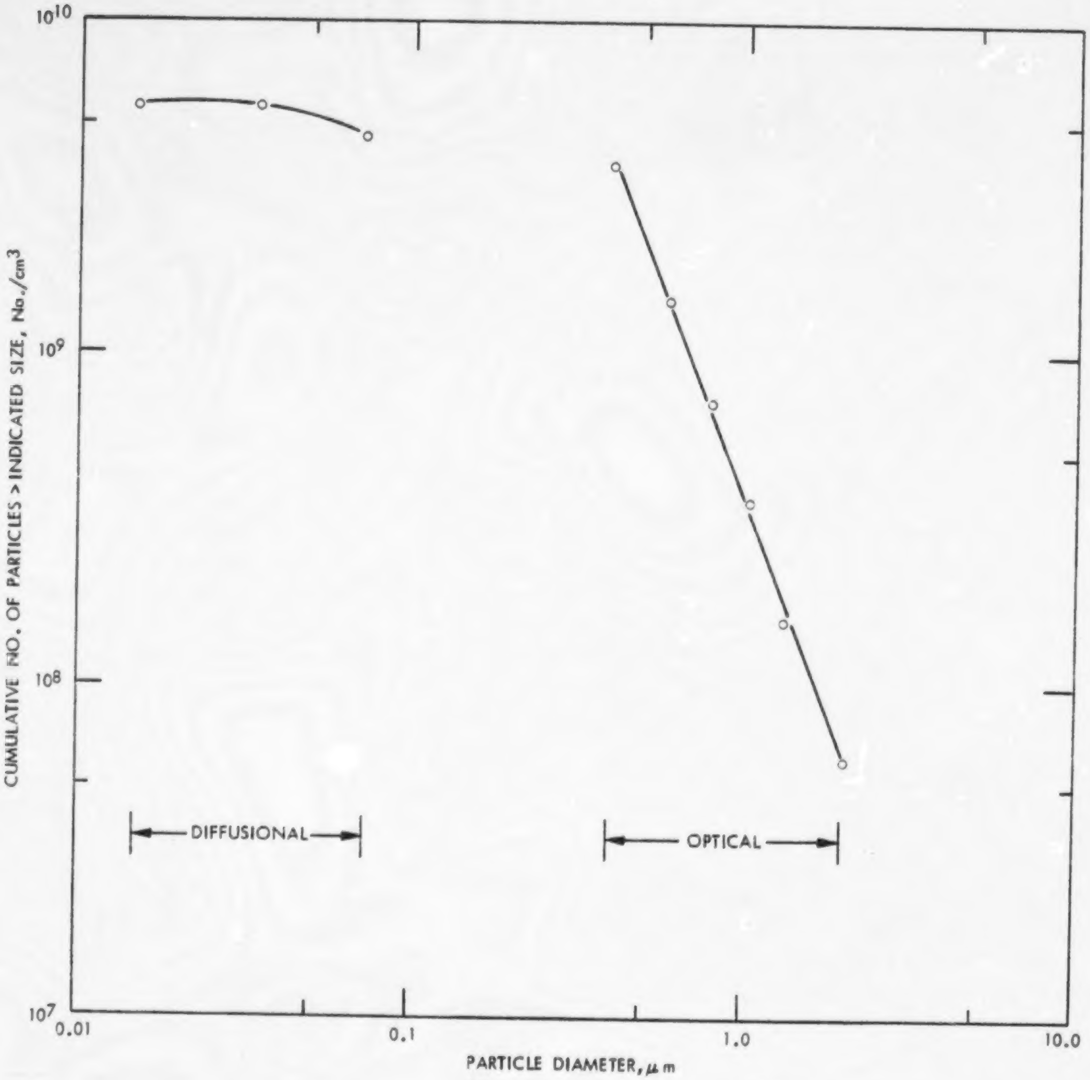


Figure 4. Inlet particle size distribution - Run 1 (optical and diffusional).

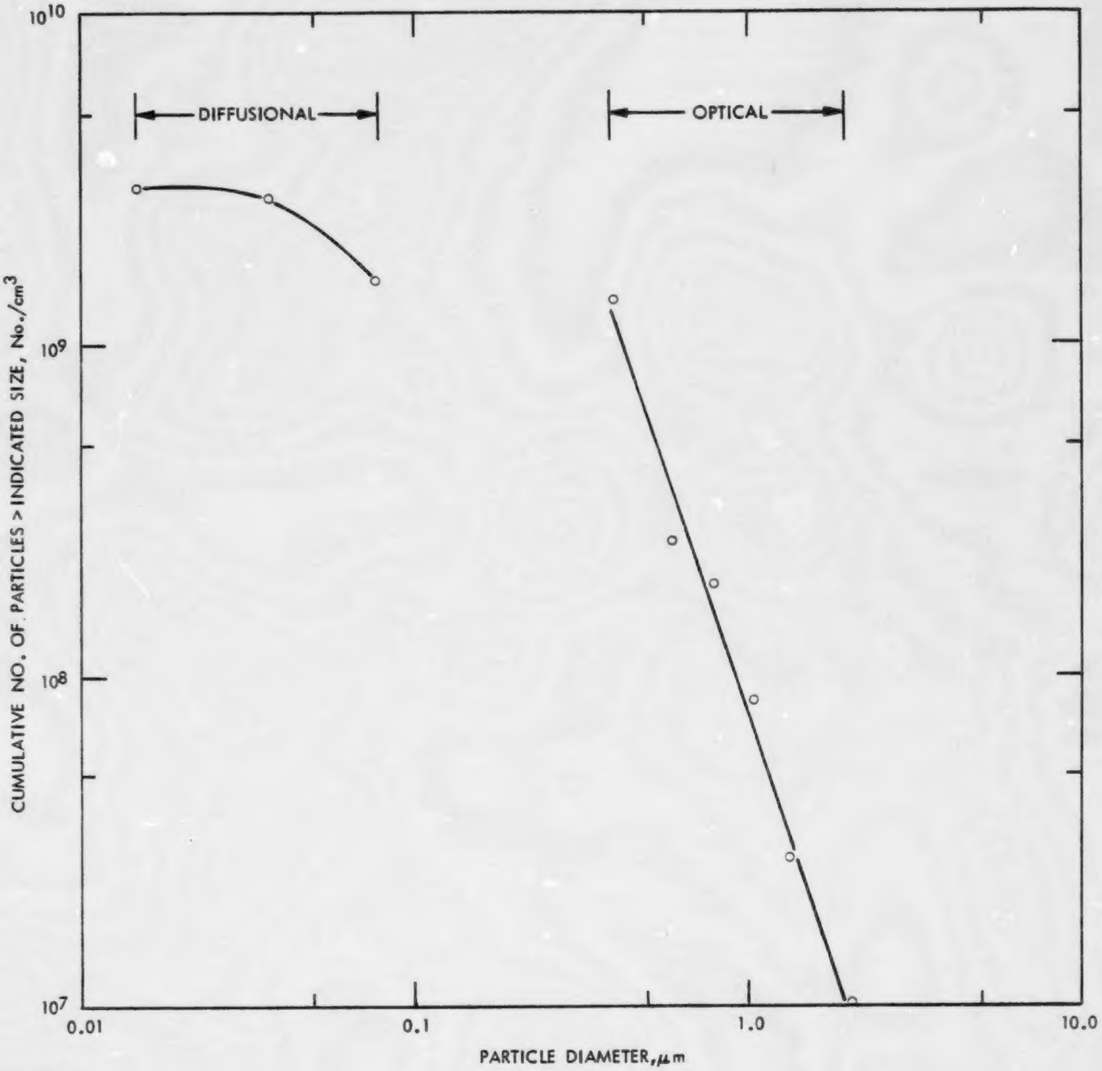


Figure 5. Inlet particulate size distribution - Run 2 (optical and diffusional).

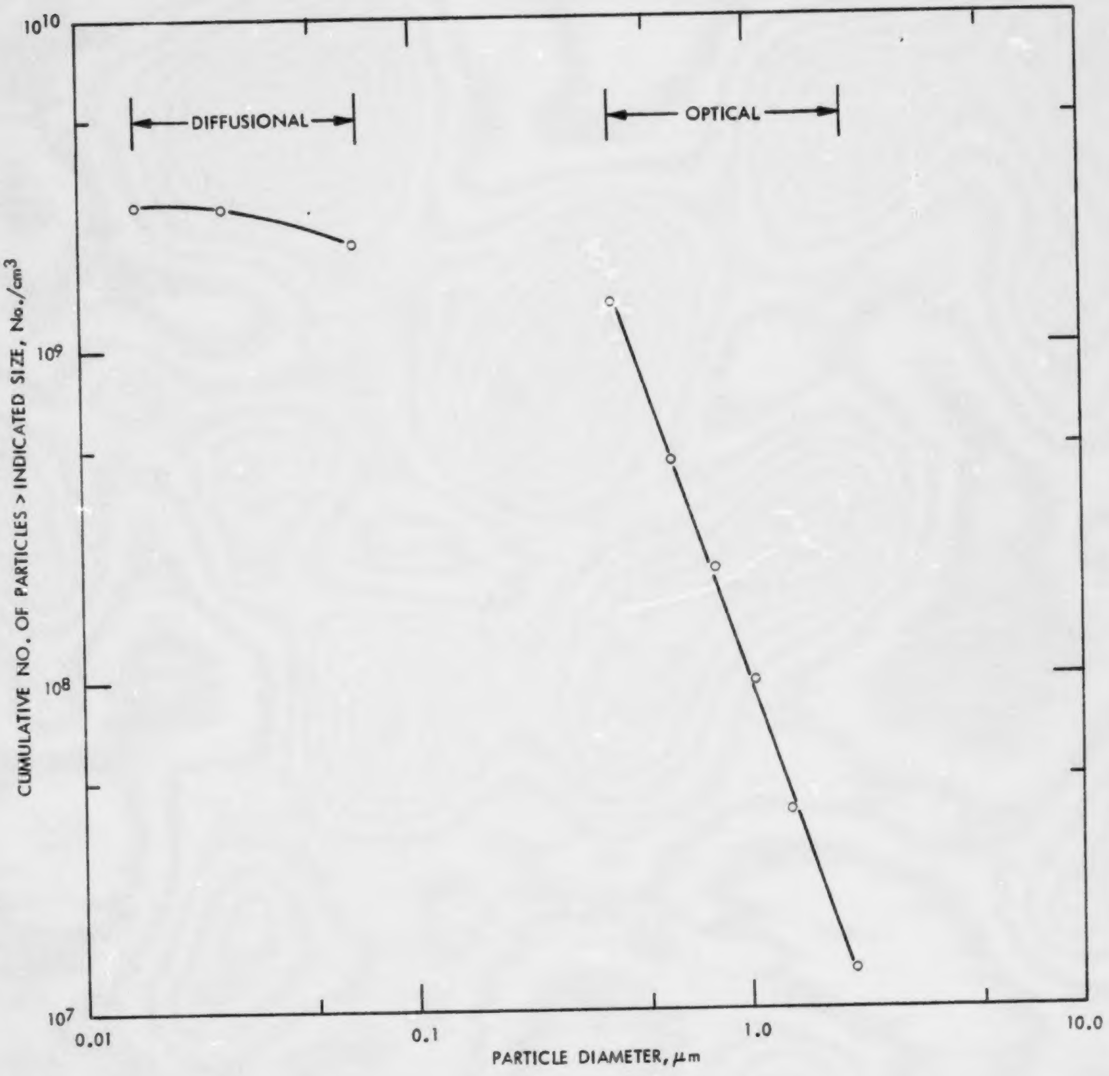


Figure 6. Inlet particle size distribution - Run 3 (optical and diffusional).

During the planning for this test program, it was anticipated that the quantities of fly ash captured by the tandem collectors could be measured on a unit time basis. But because of the pneumatic ash removal system, a direct measurement of fly ash quantities was not possible. As an alternative measurement method, the removal system was blocked off and the hoppers were allowed to fill over the course of the test period. At the end of the test day when the boiler was shut down, the depth of material in the hoppers was to be measured and the quantities of fly ash calculated. However, at the conclusion of the first test day, the ash levels in the primary hoppers were well above the access doors which precluded access to the interiors of the hoppers for measurement of ash depth.

Personnel from UOP/Air Correction Division, the suppliers of the mechanical collectors, were at the test site on the 2nd day and provided assistance in this effort. When testing was completed and the boiler shut down, the UOP crew evacuated the secondary collector hoppers via a vacuum system and quantitated the material using 19 liter drums. The primary collector hoppers could not be emptied by this method because of the large amount of ash involved.

The ash capture rate of the secondary collector was determined to be 4.9 kg/hr by UOP. The primary catch can be estimated using results of the MRI particulate tests. The difference between the inlet and outlet emission rates was 183.9 kg/hr, which should correspond to the total amount of fly ash collected by both multiclones. Therefore, the primary collector capture rate should have been approximately 179 kg/hr. If the same primary/secondary capture ratio is assumed for the first test day, the ash collection rates would be 222 kg/hr for the primary collector and 6.3 kg/hr for the secondary collector. The reason for the greater amounts of collector ash on the first day could not be readily explained.

SSMS analysis results showing elemental composition of the primary and secondary collector ashes are presented in Tables 18 and 19, respectively. In general, there were distinct increases of elemental concentrations in the secondary ash relative to the primary ash. The elements detected at the highest concentrations were basically the same elements that were most prominent in the bottom ash. Those identified as major components (> 1,000 μg/g) included Fe, Ti, Ca, K, S, P, Si, Al, Mg, and Na. These elements were present as major components in both primary and secondary ash. In the secondary ash, additional major elements were Ba, Sr, Mn, and F. Other elements of interest which were observed in the secondary ash at moderately high concentrations were As, Ni, Cr, V, and Cl. Levels of lead, mercury, antimony, and beryllium were low (< 10 μg/g) in both ashes.

Table 20 presents a comparison of elemental concentrations in the bottom ash, primary collector ash, and secondary collector ash. This comparison is noteworthy because it is apparent that many elements are most concentrated in the secondary collector ash, which has the smallest mean particle size of the three ash types.

TABLE 18. ELEMENTAL ANALYSIS OF PRIMARY COLLECTOR ASH BY SSMS CONCENTRATION (μg/g)

	Concentration (μg/g)			
Element	Run 1	Run 1 Duplicate	Runs 2 and 3	Range
Uranium	6	3	≤ 2	≤ 2 - 6
Thorium	10	7	2	2 - 10
Bismuth	< 0.02	< 0.02	< 0.2	< 0.2
Lead	9	8	4	4 - 9
Thallium	< 0.02	< 0.02	< 0.2	< 0.2
Mercury	NR	NR	0.66a/	-
Gold	< 0.02	< 0.02	< 0.2	< 0.2
Platinum	< 0.02	< 0.02	< 0.2	< 0.2
Iridium	< 0.02	< 0.02	< 0.2	< 0.2
Osmium	< 0.02	< 0.02	< 0.2	< 0.2
Rhenium	< 0.02	< 0.02	< 0.2	< 0.2
Tungsten	1	< 0.02	< 0.2	< 0.2 - 1
Tantalum	< 0.02	< 0.02	< 0.2	< 0.2
Hafnium	1	1	< 0.2	< 0.2 - 1
Lutetium	0.3	< 0.02	< 0.2	< 0.02 - 0.3
Ytterbium	2	< 0.02	< 0.2	< 0.02 - 2
Thulium	0.2	0.2	< 0.2	< 0.2 - 0.2
Erbium	1	0.7	< 0.2	< 0.2 - 1
Holmium	2	1	< 0.2	< 0.2 - 2
Dysprosium	3	2	< 0.2	< 0.2 - 3
Terbium	1	0.6	0.2	0.2 - 1
Gadolinium	3	2	0.6	0.6 - 3
Europium	1	0.8	0.5	0.5 - 1
Samarium	11	6	3	3 - 11
Neodymium	12	8	9	8 - 12
Praseodymium	6	4	3	3 - 6
Cerium	31	25	31	25 - 31
Lanthanum	25	22	22	22 - 25
Barium	MC	510	450	450-> 1,000
Cesium	1	1	0.8	0.8 - 1
Iodine	2	2	1	1 - 2
Tellurium	< 0.02	< 0.02	< 0.2	< 0.2
Antimony	2b/	2	1	1 - 2
Tin	2	1	0.6	0.6 - 2
Indium	STD	STD	STD	-
Cadmium	0.7	≤ 0.3	0.4	≤ 0.3 - 0.7
Silver	0.2	0.2	< 0.2	< 0.2 - 0.2
Palladium	< 0.02	< 0.02	< 0.2	< 0.2
Rhodium	< 0.02	< 0.02	< 0.2	< 0.2
Ruthenium	< 0.02	< 0.02	< 0.2	< 0.2
Molybdenum	6	5	59a/	5 - 59
Niobium	12	9	11	9 - 12
Zirconium	120	61	55	55 - 120
Yttrium	31	18	28	18 - 31
Strontium	380	460	460	380 - 460
Rubidium	28	41	15	15 - 41
Bromine	17	19	24	17 - 24
Selenium	7	10	10	7 - 10
Arsenic	99b/	60	58	58 - 99
Germanium	5	5	5	5
Gallium	26	18	28	18 - 28
Zinc	39	62	110	39 - 110
Copper	64	64	63	63 - 64
Nickel	25	22	35	22 - 35
Cobalt	8	7	11	7 - 11
Iron	MC	MC	MC	> 1,000
Manganese	350	720	270	270 - 720
Chromium	120	110	110	110 - 120
Vanadium	140	130	160	130 - 160
Titanium	MC	MC	MC	> 1,000
Scandium	14	12	12	12 - 14
Calcium	MC	MC	MC	> 1,000
Potassium	MC	MC	MC	> 1,000
Chlorine	600b/	96	120	96 - 600
Sulfur	MC	MC	MC	> 1,000
Phosphorus	MC	MC	MC	> 1,000
Silicon	MC	MC	MC	> 1,000
Aluminum	MC	MC	MC	> 1,000
Magnesium	MC	MC	MC	> 1,000
Sodium	MC	MC	MC	> 1,000
Fluorine	≈ 840	≈ 330	≈ 250	250 - 840
Oxygen	NR	NR	NR	-
Nitrogen	NR	NR	NR	-
Carbon	NR	NR	NR	-
Boron	100	40	16	16 - 100
Beryllium	4	3	2	2 - 4
Lithium	74	30	20	20 - 74

Note: NR = not reported
MC = major component, > 1,000 μg/g
STD = internal standard

a/ Flameless atomic absorption

b/ Heterogenous

TABLE 19. ELEMENTAL ANALYSIS OF SECONDARY COLLECTOR ASH BY SSMS

Element	Concentration (μg/g) Run 1	Run 1 Duplicate	Runs 2 and 3	Range	Element	Concentration (μg/g) Run 1	Run 1 Duplicate	Runs 2 and 3	Range
Uranium	17	11	7	7 - 17	Ruthenium	< 0.6	< 0.6	< 0.4	< 0.6
Thorium	25	23	15	15 - 25	Molybdenum	33	34	51	33 - 51
Bismuth	< 0.6	< 0.6	< 0.4	< 0.6	Niobium	38	78	52	38 - 78
Lead	5	4	3	3 - 5	Zirconium	190	190	130	130 - 190
Thallium	< 0.6	< 0.6	< 0.4	< 0.6	Yttrium	96	89	150	89 - 150
Mercury	NR	NR	5.87[a]	-	Strontium	940	MC	MC	> 940
Gold	< 0.6	< 0.6	< 0.4	< 0.6	Rubidium	42	59	98	42 - 98
Platinum	< 0.6	< 0.6	< 0.4	< 0.6	Bromine	28	26	31	26 - 31
Iridium	< 0.6	< 0.6	< 0.4	< 0.6	Selenium	72	83	140	72 - 140
Osmium	< 0.6	< 0.6	< 0.4	< 0.6	Arsenic	380	630	940	380 - 940
Rhenium	< 0.6	< 0.6	< 0.4	< 0.6	Germanium	16	31	41	16 - 41
Tungsten	5	3	3	3 - 5	Gallium	97	220	150	97 - 220
Tantalum	< 0.6	< 0.6	< 0.4	< 0.6	Zinc	48	89	130	48 - 130
Hafnium	< 0.6	7	3	< 0.6 - 7	Copper	99	230	150	99 - 230
Lutetium	0.7	< 0.6	0.5	< 0.6 - 0.7	Nickel	240	280	370	240 - 370
Ytterbium	4	3	3	3 - 4	Cobalt	56	69	46	46 - 69
Thulium	1	0.5	0.4	0.4 - 1	Iron	MC	MC	MC	> 1,000
Erbium	3	2	2	2 - 3	Manganese	MC	MC	MC	> 1,000
Holmium	3	3	2	2 - 3	Chromium	93	620	410	93 - 620
Dysprosium	4	4	4	4	Vanadium	440	MC	450	440-> 1,000
Terbium	2	1	0.9	0.9 - 2	Titanium	MC	MC	MC	> 1,000
Gadolinium	6	4	2	2 - 6	Scandium	43	79	53	43 - 79
Europium	3	2	1	1 - 3	Calcium	MC	MC	MC	> 1,000
Samarium	15	14	9	9 - 15	Potassium	MC	MC	MC	> 1,000
Neodymium	33	19	22	19 - 33	Chlorine	330	380	340	330 - 380
Praseodymium	15	9	16	9 - 16	Sulfur	MC	MC	MC	> 1,000
Cerium	170	99	110	99 - 170	Phosphorus	MC	MC	MC	> 1,000
Lanthanum	61	94	100	61 - 100	Silicon	MC	MC	MC	> 1,000
Barium	MC[b]	MC	MC	> 1,000	Aluminum	MC	MC	MC	> 1,000
Cesium	3	3	7	3 - 7	Magnesium	MC	MC	MC	> 1,000
Iodine	9	3	0.9	0.9 - 9	Sodium	MC	MC	MC	> 1,000
Tellurium	≤ 1	< 0.6	≤ 0.8	≤ 1	Fluorine	MC	MC	MC	> 1,000
Antimony	14	11	16	11 - 16	Oxygen	NR	NR	NR	> 1,000
Tin	5	5	4	4 - 5	Nitrogen	NR	NR	NR	-
Indium	STD	STD	STD	-	Carbon	NR	NR	NR	-
Cadmium	2	1	1	1 - 2	Boron	270	140	190	140 - 270
Silver	≤ 1	≤ 0.6	0.5	≤ 1	Beryllium	5	8	5	5 - 8
Palladium	< 0.6	< 0.6	< 0.4	< 0.6	Lithium	100	42	28	28 - 100
Rhodium	< 0.6	< 0.6	< 0.4	< 0.6					

Note: NR = not reported.
MC = major component, > 1,000 μg/g.
STD = internal standard.

[a] Flameless atomic absorption.

[b] Heterogeneous.

TABLE 20. COMPARISON OF ELEMENTAL ANALYSES OF ASH MATERIALS

Element	Average[a] Bottom Ash	Average[a] Primary Collector Ash	Average[a] Secondary Collector Ash
Uranium	7.5	4.5	14
Thorium	13.5	8.5	24
Bismuth	-	-	-
Lead	6	8.5	4.5
Thallium	-	-	-
Mercury	(0.09)[b]	(0.66)[b]	(5.87)[b]
Gold	-	-	-
Platinum	-	-	-
Iridium	-	-	-
Osmium	-	-	-
Rhenium	-	-	-
Tungsten	2.5	-	4
Tantalum	-	-	-
Hafnium	3.5	1	-
Lutetium	0.35	-	-
Ytterbium	2	-	3.5
Thulium	0.35	0.2	0.75
Erbium	1.5	0.85	2.5
Holmium	2	1.5	3
Dysprosium	3.5	2.5	4
Terbium	0.9	0.8	1.5
Gadolinium	2.5	2.5	5
Europium	1	0.9	2.5
Samarium	10.5	8.5	14.5
Neodymium	20	10	26
Praseodymium	9.5	5	12
Cerium	78	28	135
Lanthanum	57	24	78
Barium	MC	MC	MC
Cesium	4.5	1	3
Iodine	-	2	6
Tellurium	-	-	0
Antimony	3	2	12
Tin	2	1.5	5
Indium	STD	STD	STD
Cadmium	-	-	1.5
Silver	-	0.2	-
Palladium	-	-	-
Rhodium	-	-	-
Ruthenium	-	-	-
Molybdenum	10	6	34
Niobium	48	10	58
Zirconium	MC	90	190
Yttrium	104	24	92
Strontium	MC	420	MC
Rubidium	100	34	50
Bromine	1.5	18	27
Selenium	2.5	8.5	78
Arsenic	14	80	510
Germanium	5	5	24
Gallium	42	22	160
Zinc	36	50	68
Copper	94	64	160
Nickel	74	24	260
Cobalt	42	8	62
Iron	MC	MC	MC
Manganese	MC	540	MC
Chromium	360	120	360
Vanadium	260	140	MC
Titanium	MC	MC	MC
Scandium	65	13	61
Calcium	MC	MC	MC
Potassium	MC	MC	MC
Chlorine	27	350	360
Sulfur	MC	MC	MC
Phosphorus	MC	MC	MC
Silicon	MC	MC	MC
Alumium	MC	MC	MC
Magnesium	MC	MC	MC
Sodium	MC	MC	MC
Fluorine	134	580	MC
Oxygen	NR	NR	NR
Nitrogen	NR	NR	NR
Carbon	NR	NR	NR
Boron	66	70	205
Beryllium	6	4	6
Lithium	720	52	71

Note: NR = not reported.
MC = major component, > 1,000 μg/g.
STD = internal standard.

[a] Based on an average of two values.

[b] Based on one value.

Another interesting trend is exhibited by Hg, Br, Se, As, Cl, F, and B. Each of these elements shows progressively increasing concentrations from bottom ash to primary collector ash to secondary collector ash. Since these elements are relatively volatile, their presence in the primary and secondary collector ash suggests that a condensation mechanism may be responsible for the observed increases in concentrations with decreasing particle size.

Analysis of the collector ash samples for PCB materials did not yield any confirmed responses. The primary ash samples were eliminated from further consideration after the initial EC/GC screening. Secondary ash samples were also analyzed using GC/MS, but no positive signals were observed at the 0.05 μg/g detection limit.

The primary and secondary collector ashes were also analyzed for PAH compounds. No PAH materials were detected in any of the primary ash extracts. However, positive confirmation of several compounds resulted from analysis of the secondary collector ash. These data are shown in Table 21. The compounds identified were acenaphthylene, phenanthrene, fluoranthene, and pyrene. The highest sample concentration observed (10 μg/g) was that of phenanthrene in the secondary ash sample collected on the 2nd day of testing.

CONTROLLED AIR EMISSIONS (COLLECTOR OUTLET)

The air stream emitted from the mechanical collectors was extensively characterized due to its importance as a pollutant stream. Flue gas parameters assessed for the test program included:

- Gas composition (O_2, CO_2, NO_x, SO_2, CO, and HC);
- Particulate mass concentration;
- Particulate elemental analysis;
- Particle size distribution;
- Opacity;
- PCB and PAH compounds; and
- EPA Level 1 assessment using SASS.

Results of these analyses are discussed individually below.

TABLE 21. ANALYSIS OF SECONDARY COLLECTOR ASH FOR PAH BY GC/MS

Compound	Detection limit[a] (µg/g)	Run 1[b] (µg/g)	Run 1 duplicate (µg/g)	Run 2[b] (µg/g)
Acenaphthylene	0.56[c]	2.2	2.5	-
Fluorene	0.54[c]	-	-	-
Phenanthrene	0.24[c]	6.0	3.5	10
Anthracene	0.15[c]	-	-	-
Fluoranthene	0.17[c]	1.6	0.62	3.5
Pyrene	0.16[c]	0.9	0.32	1.0
Chrysene	0.50[d]	-	-	-
1,2-Benzanthracene	0.47[c]	-	-	< 0.47[e]
Benzo[a]pyrene	6.7[c]	-	-	-
Perylene	0.56[d]	-	-	-
Indeno[1,2,3-c,d]pyrene	1.5[d]	-	-	-
1,2,5,6-Dibenzanthracene	2.2[d]	-	-	-
1,12-Benzoperylene	1.4[d]	-	-	-

a/ Assuming a 20 g sample weight and a 1,000 counter minimum signal.

b/ Values corrected to D-10 anthracene internal standard.

c/ Based on response factors determined using 1 µl of a 1 ng/µl standard.

d/ Based on response factors determined using 1 µl of a 5 ng/µl standard.

e/ Compound identity could not be verified by GC/MS.

Gas Composition

During the course of air emissions testing, the exhaust gases were continuously monitored for levels of O_2, NO_x, SO_2, CO, and THC. Concentrations of CO_2 and O_2 were also periodically measured using Orsat and Fyrite gas analysis. The continuous monitors were operated during the entire period of testing each day. Results are displayed in Table 22.

Oxygen and carbon dioxide levels remained relatively constant throughout the test program. Concentrations of O_2 in the exhaust stream, as determined by the continuous monitor, averaged 13.0 and 12.1% on the first and 2nd days, respectively. The Fyrite analysis yielded slightly different values of 12.7 and

TABLE 22. BOILER EXHAUST GAS COMPOSITION[a]

Date	Time	O_2 (%)		CO_2 (%)[d]		SO_2 (ppm)[c]		CO (ppm)		THC (ppm)[d]		NO_x (ppm)	
		Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
7/24	11:45-17:00	13.0	12.6-13.3	7.9	7.9	155	110-230	180	135-225	7	2-13	68	60-77
7/25	09:00-16:00	12.1	11.4-12.6	7.3	6.8-7.9	120	90-160	245	125-400	10	4-21	64	57-71

a/ Gas samples were drawn from the duct downstream from the mechanical collectors and were analyzed by continuous monitoring equipment. Averages were computed from data points transcribed from the strip chart records at 15 min intervals.

b/ Determined with a Fyrite analyzer.

c/ H_2O interference contributed about 20 ppm to all SO_2 readings. Values shown have been corrected for this discrepancy.

d/ Total hydrocarbon results were reported as propane.

12.9%, by comparison. Fyrite analyzers, however, are usually only accurate to within about 1%. CO_2 concentrations averaged 7.9% on the first test day and 7.3% on the second.

Excess air in the gas stream downstream of the collector was calculated using the Fyrite data and showed very little variation ($\pm$ 2%) during the study. The average value for measurements which correspond to the three particulate tests was 155% excess air. Since the excess air values determined upstream of the mechanical collectors varied between 103 and 197%, these observed readings may have been the result of incomplete mixing of the flue gases.

Concentrations of CO appeared to be a little high, averaging 180 ppm the first day and 245 ppm on the second. Readings as high as 400 ppm were observed during the last day of testing. It is possible that incomplete combustion of some of the wood chips could have led to elevated CO levels, although it would seem that the overfire air introduced with the fuel oil above the combustion grate should have aided in completing the combustion of any suspended wood particles. Nonetheless, some charred, wood-like particles were observed in the primary ash samples.

SO_2 concentrations were fairly low, and most likely would have been even lower if the wood chips were not "contaminated" with coal dust particles as described earlier. Theoretically, if it is assumed that all of the sulfur in wood (0.1%) is released as SO_2, the SO_2 concentration should have been only about 38 to 46 ppm if wood were used as the sole fuel. Similarly, theoretical maximum emissions of SO_2 from combustion of the fuel oil alone during testing would have been about 10 ppm.

Emissions of nitrogen oxides and THCs were both very low. NO_x levels varied from 57 to 77 ppm over the two test days, while THC concentrations were in the range of 2 to 21 ppm.

Particulate Mass Concentration

Results of the EPA Method 5 particulate concentration determinations are presented in Tables 23 and 24 in both metric and English units. The uncontrolled emission data are included for comparative purposes.

The total particulate concentration averaged 0.177 g/dscm (0.077 gr/dscf), of which 0.143 g/dscm was filterable material. On a heat input basis, the total emission rate averaged 0.094 g/MJ (0.166 lb/10^6 Btu).

On August 12, 1978, the Vermont Agency of Environmental Conservation adopted new air pollution control regulations for wood fired boilers (where wood fuel contributes 50% or more of the total Btu input) operating in the state. For Unit No. 1 at Burlington Electric, which commenced operation with wood fuel prior to December 5, 1977, the particulate emission limitation is 0.45 grains per dry

TABLE 23. SUMMARY OF PARTICULATE TEST RESULTS (METRIC UNITS)

			Flue gas parameters					Particulate concentration (g/dscm)		Particulate emission rate				Collector efficiency (%)	
										(kg/hr)		(g/MJ)			
Test No.	Date	Location	Moisture content (%)	Avg. temp. (°C)	Flow rate (dscmm)	% O_2	% CO_2	Front half[a]	Total[b]	Front half	Total	Front half	Total	Front half	Total
1	7/24/78	Inlet	10.0	154	1,210	12.5	7.7	3.32	3.36	241	244	1.75	1.78		
		Outlet	9.3	146	1,301	12.7	7.9	0.163	0.192	13	15	0.095	0.109	95.1	94.3
2	7/25/78	Inlet	11.9	159	1,162	10.5	11.0	2.62	2.77	183	193	1.26	1.33		
		Outlet	10.4	158	1,246	12.8	7.4	0.173	0.204	13	15	0.089	0.103	93.4	92.6
3	7/25/78	Inlet	12.0	167	1,160	14.0	6.0	2.94	2.97	205	207	1.41	1.43		
		Outlet	12.1	154	1,253	12.9	7.1	0.093	0.134	7	10	0.048	0.069	96.8	95.5
Average		Inlet	11.3	160	1,177	12.3	8.2	2.96	3.03	210	215	1.47	1.51		
		Outlet	10.6	153	1,267	12.8	7.5	0.143	0.177	11	13	0.077	0.094	95.1	94.2

[a] "Front half" refers to filterable particulate only (i.e., filter catch plus rinses of probe and connections).

[b] "Total" values include contents of impinger solutions (condensibles).

TABLE 24. SUMMARY OF PARTICULATE TEST RESULTS (ENGLISH UNITS)

			Flue gas parameters					Particulate concentration (gr/dscf)		Particulate emission rate (lb/hr)		Particulate emission rate ($lb/10^6$ Btu)		Collector efficiency (%)	
Test No.	Date	Location	Moisture content (%)	Avg. temp. (°F)	Flow rate (dscfm)	% O_2	% CO_2	Front half[a]	Total[b]	Front half	Total	Front half	Total	Front half	Total
1	7/24/78	Inlet	10.0	310	42,700	12.5	7.7	1.45	1.47	531	538	2.86	2.90		
		Outlet	9.3	294	46,000	12.7	7.9	0.071	0.084	28	33	0.151	0.178	95.1	94.3
2	7/25/78	Inlet	11.9	318	41,000	10.5	11.0	1.15	1.21	403	425	1.96	2.07		
		Outlet	10.4	317	44,000	12.8	7.4	0.076	0.089	28	34	0.136	0.214	93.4	92.6
3	7/25/78	Inlet	12.0	333	41,000	14.0	6.0	1.29	1.30	451	456	2.19	2.22		
		Outlet	12.1	309	44,200	12.9	7.1	0.041	0.058	15	22	0.073	0.107	96.8	95.5
Average		Inlet	11.3	320	41,600	12.3	8.2	1.29	1.33	462	473	2.34	2.40		
		Outlet	10.6	307	44,700	12.8	7.5	0.063	0.077	24	30	0.120	0.166	95.1	94.2

[a] "Front half" refers to filterable particulate only (i.e., filter catch plus rinses of probe and connections).

[b] "Total" values include contents of impinger solutions (condensibles).

standard cubic foot (gr/DSCF) of exhaust gas corrected to 12% CO_2. The average emission concentration measured by MRI was 0.10 gr/DSCF. Therefore, the boiler easily complies with the new state regulations.

Measured efficiencies of the mechanical collection system were very good, averaging 95.1% of the filterable particulate. Values ranged from 93.4 to 96.8%. When condensible particulate was included, the average efficiency dropped slightly to 94.2%.

Particulate Elemental Composition

After gravimetric analysis of the Method 5 filter particulate, elemental composition of the samples was determined using SSMS. Table 25 presents the resulting data.

As was the case with SSMS analysis of the inlet particulate filter samples, several elemental concentrations were obscured by background levels in the filter substrate. The concentrations of those elements which could be quantified were generally higher than corresponding levels in the other particulate samples (bottom ash, collector ash, or inlet particulate). Elements with concentrations greater than 100 µg/g, as well as some elements whose hazard potential is of interest, are shown in Table 26. The data in the table are presented on the basis of an air emission concentration (µg/dscm).

A review of the data in Table 26 indicates moderate air concentrations for most of the elements listed. Those approaching 100 µg/dscm are lead, barium, strontium, zinc, and titanium.

Particle Size Distribution

The particle counting system employed at the mechanical collector outlet was identical to that used at the inlet. The mode of operation was also identical.

Table 27 summarizes the data output of the optical counter portion of the sizing system, while data from the diffusional portion is shown in Tables 28 and 29. Similar to the inlet data, no values are available for the size region above 2.6 µm.

Figures 7 through 10 are graphical representations of the outlet particle size data. The curves shown in these figures parallel those obtained for the uncontrolled particulate stream. However, the absolute number of particles in each size range is greater in the outlet stream compared to the inlet. This is most easily seen in Figure 10, in which the average cumulative size distributions for both streams have been plotted. The discontinuity between the diffussional and optical portions of the particle size curve is due to the nonoverlapping nature of the two particle counting systems.

TABLE 25. ELEMENTAL ANALYSIS OF OUTLET METHOD 5 FILTER PARTICULATE BY SSMS

	Concentration (µg/g)				
Element	Run 1a/	Run 1 duplicateb/	Run 2c/	Run 3d/	Range
Uranium	-	0.4	-	-	
Thorium	-	-	-	-	
Bismuth	-	0.6	≥ 0.05e/	1e/	
Lead	200	300	400	> 900	200-> 900
Thallium	5	10	20	70	5-70
Mercury	59.8f/	46.6f/	20f/	64.0f/	20-64
Gold	-	-	-	≤ 0.3e,g/	
Platinum	-	-	-	-	
Iridium	-	-	-	-	
Osmium	-	-	-	-	
Rhenium	-	-	-	-	
Tungsten	-	-	-	-	
Tantalum	-	-	-	-	
Hafnium	-	-	-	-	
Lutetium	-	-	-	-	
Ytterbium	-	-	-	-	
Thulium	-	-	-	-	
Erbium	-	-	-	-	
Holmium	-	-	-	-	
Dysprosium	-	-	-	-	
Terbium	-	-	-	-	
Gadolinium	-	-	-	-	
Europium	-	-	-	-	
Samarium	-	-	-	-	
Neodymium	5	0.5	4	8	0.5-8
Praseodymium	2	0.6	-	6	0.6-6
Cerium	30	6	30	40	6-40
Lanthanum	10	10	40	60	10-60
Barium	500	100	> 500	> 900	100-> 900
Cesium	2	0.6	2	4	0.6-4
Iodine	10	10	16	40	10-40
Tellurium	-	-	-	-	
Antimony	6	6	11	50	6-50
Tin	10	6	11	50	6-50
Indium	STD	STD	STD	STD	
Cadmium	2	2	≤ 0.05e/	40	
Silver	4	2	30	9	2-30
Palladium	-	-	-	-	
Rhodium	-	-	-	-	
Ruthenium	-	-	-	-	
Molybdenum	10	10	16	60	10-60
Niobium	4	2	5	20	2-20
Zirconium	30	10	20	200	10-200
Yttrium	10	4	10	30	4-30
Strontium	200	60	300	> 900	60-> 900
Rubidium	40	30	50	90	20-90
Bromine	50	60	100	300	50-300
Selenium	60	20	50	300	20-300
Arsenic	400	200	300	200	200-400
Germanium	20	20	30	200	20-200
Gallium	200	20	100	400	20-400
Zinc	> 600	> 600	> 500	> 900	
Copper	300	100	100	800	100-800
Nickel	200	20	20e/	300	20-300
Cobalt	< 0.06e/	4	< 0.05e/	< 0.03e/	
Iron	> 600	> 600	> 500	> 900	
Manganese	> 400	60	> 200	> 900	60-> 900
Chromium	< 0.06e/	20	< 0.05e/	< 0.3e/	
Vanadium	60	10	40	200	10-200
Titanium	> 600	>100	> 500	> 900	100-> 900
Scandium	5	5	0.7e/	20	0.7-20
Calcium	B	B	B	B	
Potassium	B	B	B	B	
Chlorine	B	B	B	B	
Sulfur	B	B	B	B	
Phosphorus	> 600	> 600	> 500	> 900	
Silicon	B	B	B	B	
Aluminum	B	B	B	B	
Magnesium	B	B	B	B	
Sodium	B	B	B	B	
Fluorine	B	B	B	B	
Oxygen	NR	NR	NR	NR	
Nitrogen	NR	NR	NR	NR	
Carbon	NR	NR	NR	NR	
Boron	B	B	B	B	
Beryllium	2	0.6	≤ 0.05e/	4	
Lithium	40	10	10	80	10-80
Hydrogen	NR	NR	NR	NR	

Note: B = background levels exceed analytical range.
NR = not reported.
STD = internal standard.

a/ Detection limit = 0.06 µg/g.
b/ Detection limit = 0.06 µg/g.
c/ Detection limit = 0.05 µg/g.
d/ Detection limit = 0.3 µg/g.
e/ Corrected for background levels > 20% of sample content.
f/ Flameless atomic absorption analysis.
g/ Heterogeneous signal.

TABLE 26. SELECTED ELEMENTAL CONCENTRATIONS IN CONTROLLED PARTICULATE EMISSIONS

Element	Concentration (μg/dscm)			
	Run 1	Run 2	Run 3	Range
Lead	38	69	> 101	38-> 101
Mercury	11.4	3.4	7.2	3.4-11.4
Barium	95	> 86	> 101	> 86
Antimony	1.1	1.9	5.6	1.1-5.6
Cadmium	0.38	< 0.009	4.5	< 0.009-4.5
Zirconium	5.7	3.4	22	3.4-22
Strontium	38	51	> 101	38-> 101
Bromine	9.5	17	56	9.5-56
Selenium	21	8.6	56	8.6-56
Arsenic	76	51	22	22-76
Gallium	38	17	45	17-45
Zinc	> 114	> 86	> 101	> 86
Copper	57	17	90	17-90
Nickel	38	3.4	34	3.4-38
Chromium	< 0.01	< 0.009	< 0.03	< 0.03
Vanadium	11	6.9	22	6.9-22
Titanium	> 114	> 86	> 101	> 86
Beryllium	0.38	> 0.009	0.45	< 0.009-0.45

TABLE 27. OUTLET PARTICLE SIZE DISTRIBUTION BY NUMBER AS MONITORED BY THE OPTICAL COUNTER

Size range (μm)	Particulate concentration (10^6 particles/cu m)[a]			
	Run 1	Run 2	Run 3	Average
Channel 6 (1.5-2.6)	292	17.9	25.1	112
Channel 5 (1.2-1.5)	344	46.2	59.0	150
Channel 4 (0.9-1.2)	563	448	153	388
Channel 3 (0.7-0.9)	877	318	347	514
Channel 2 (0.5-0.7)	1,530	867	888	1,100
Channel 1 (0.3-0.5)	3,500	3,250	3,080	3,280

[a] At standard conditions (29.92 in. Hg and 68°F).

TABLE 28. OUTLET PARTICLE COUNTS BY SIZE AS MONITORED BY THE DIFFUSION BATTERY/CONDENSATION NUCLEI COUNTER

Diffusion battery port No.	Particulate concentration (10^6 particles/cu m)[a]				Fractional penetration			
	Run 1	Run 2	Run 3	Average	Run 1	Run 2	Run 3	Average
0	1,133	791	791	905	1.000	1.000	1.000	1.000
1	866	791	725	794	0.764	1.000	0.917	0.877
2	550	791	435	592	0.485	1.000	0.550	0.654
3	472	462	382	439	0.417	0.584	0.483	0.485
4	283	329	369	327	0.250	0.416	0.466	0.361
5	220	198	132	183	0.194	0.250	0.167	0.202
6	79	132	93	101	0.070	0.167	0.118	0.112
7	32	66	59	52	0.028	0.083	0.075	0.057
8	23	45	26	31	0.020	0.057	0.033	0.034
9	13	12	15	13	0.011	0.015	0.019	0.014
10	12	10	10	11	0.010	0.013	0.013	0.012

[a] At standard conditions (29.92 in. Hg and 68°F).

TABLE 29. OUTLET PARTICLE SIZE DISTRIBUTION RESULTING FROM DIFFUSION BATTERY PENETRATION DATA

Run No.	Size range (μm)	No. of particles[a] (10^6 particles/cu m)	Percent of particles in stated size range
1	> 0.200	26.1	2.3
	0.030-0.200	521	46.0
	0.025-0.030	176	15.5
	0.020-0.025	86.1	7.6
	0.005-0.020	313	27.6
	< 0.005	11.3	1.0
2	> 0.055	348	44.0
	0.035-0.055	293	37.0
	0.025-0.035	103	13.0
	0.020-0.025	32.4	4.1
	< 0.020	15.1	1.9
3	> 0.110	52.2	6.6
	0.035-0.110	372	47.0
	0.030-0.035	117	14.8
	0.025-0.030	50.6	6.4
	0.005-0.025	187	23.6
	< 0.005	12.6	1.6
Average	> 0.065	215	23.7
	0.030-0.065	489	54.0
	0.025-0.030	90.5	10.0
	0.005-0.025	94.1	10.4
	< 0.005	17.2	1.9

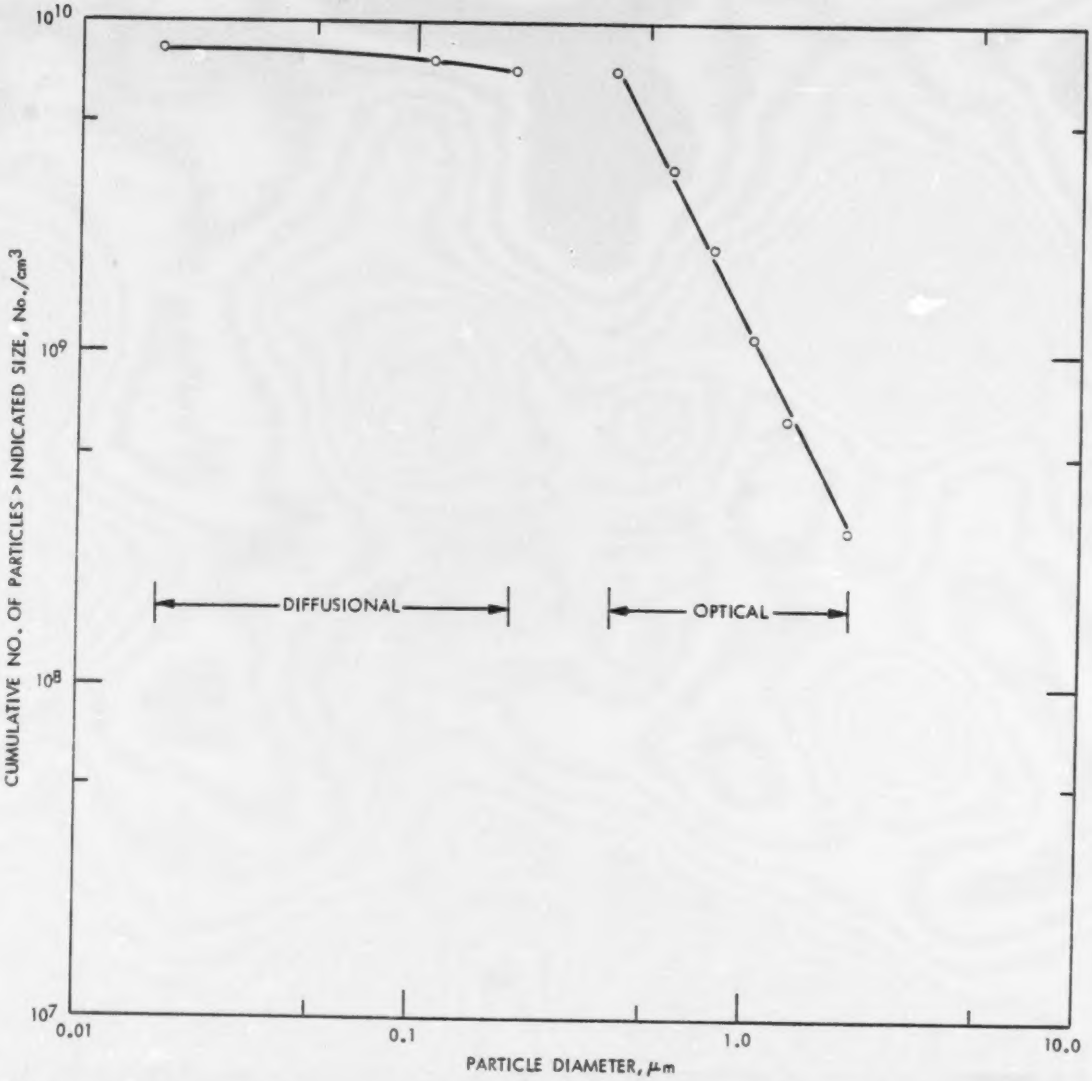


Figure 7. Outlet particle size distribution - Run 1.

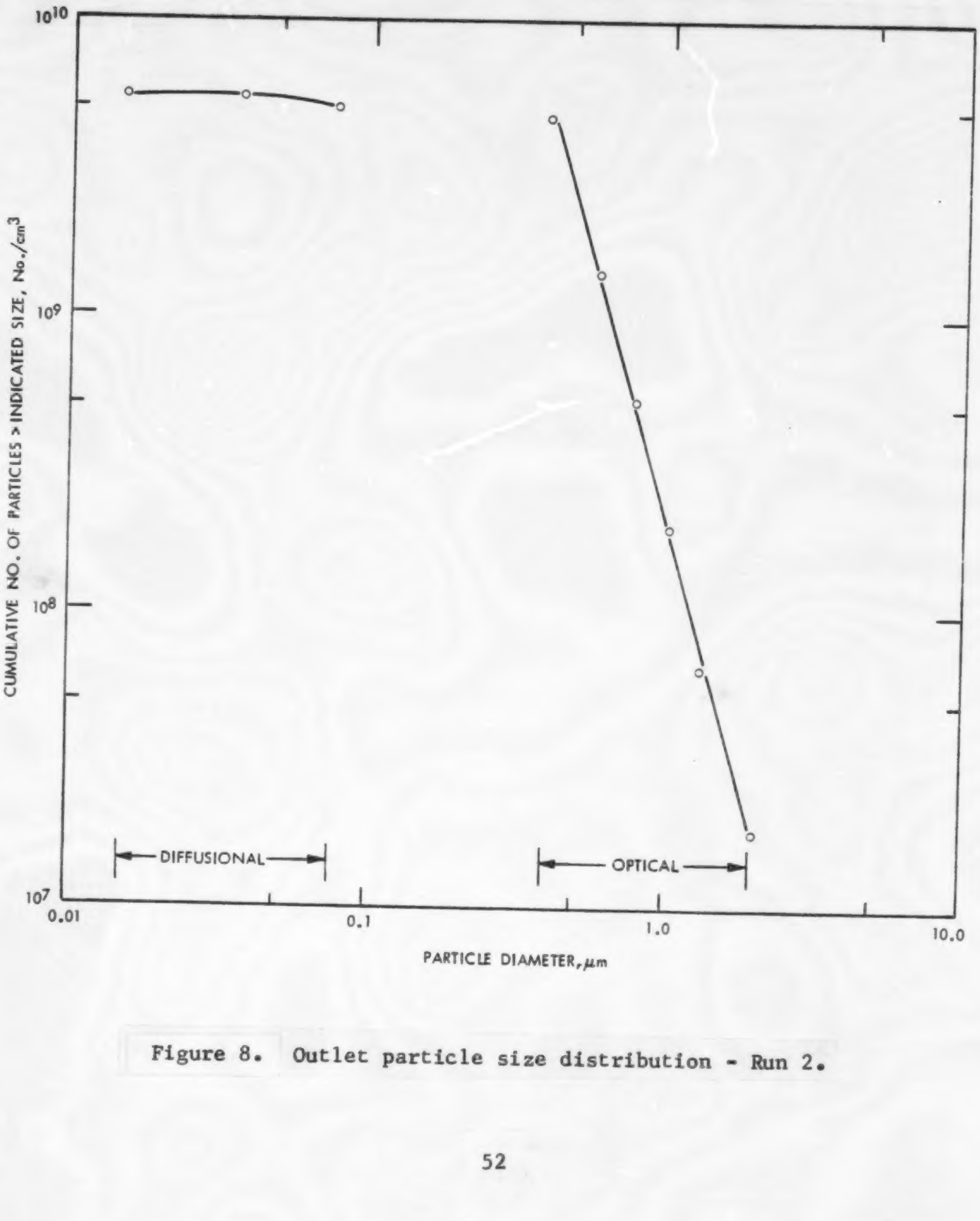


Figure 8. Outlet particle size distribution - Run 2.

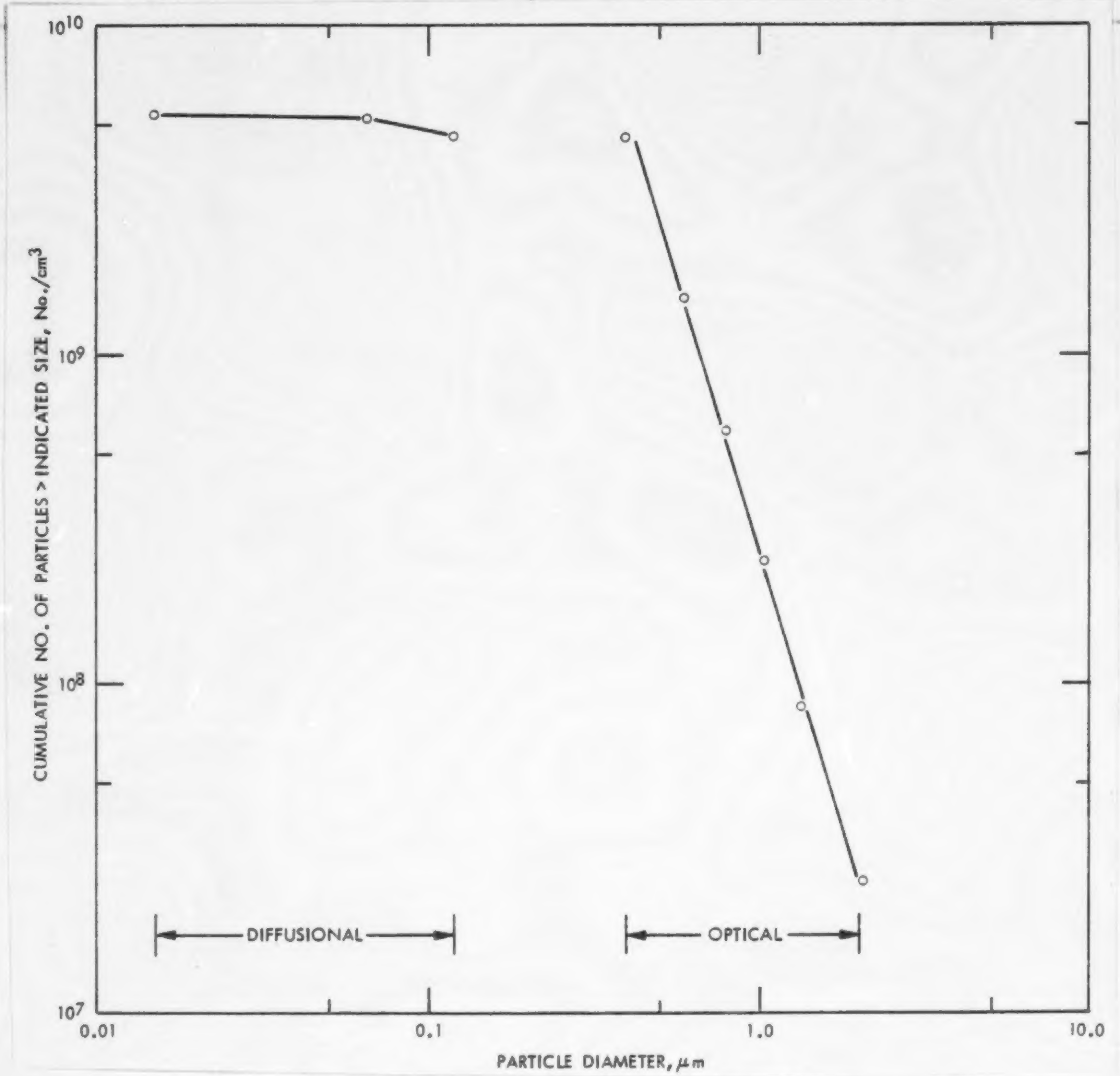


Figure 9. Outlet particle size distribution - Run 3

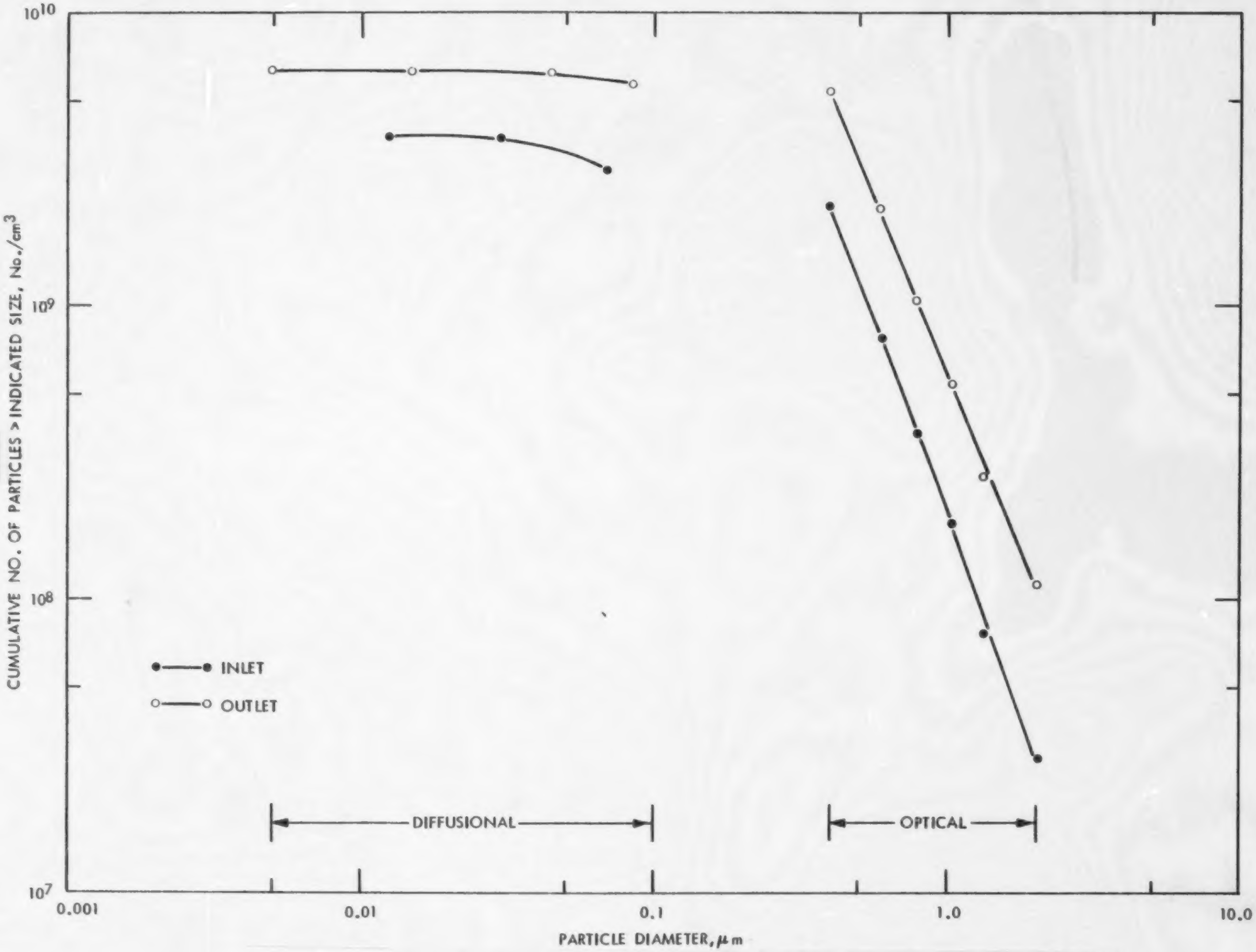


Figure 10. Average particle size distributions (inlet and outlet).

The cause of the increased numbers of small particles in the gas stream leaving the mechanical collectors is not clear. One hypothesis is that some of the particulate entering the multiclones are fractionated as a result of impaction within the collectors. If this phenomenon was indeed occurring, one would expect a more steeply sloped curve for the outlet distribution in the optical range including an intersection point with the inlet curve somewhere between 2 and 10 µm. Therefore, additional phenomena may be affecting the controlled emission stream particle size distribution.

It is not possible to make a definitive statement concerning mean particle size in the controlled emissions from the available data. However, some information about the size distribution of the collected fly ash was provided by UOP and may give a rough indication of the mean size.

Table 30 presents results of an analysis of the primary and secondary ashes which was done by UOP using a BAHCO centrifugal analyzer.

Working from the ash size analysis data and the design efficiency curves for the mechanical collectors, UOP used a computer program to simulate the particle size distributions in the air streams entering and exiting the control system. These derived distributions are shown in Table 31.

The UOP data show that, theoretically, 98.2% of the controlled particulate emissions (by weight) should have been comprised of particles smaller than 4 µm. Although this simulated distribution may be somewhat unreliable due to the inaccuracies of the BAHCO analysis and the use of design efficiency curves, it still indicates that the great majority of the particles are in the range measured by MRI's optical counter. It seems likely that the mean particle diameter is less than 1 µm.

OPACITY

Results of the EPA Method 9 visual plume opacity readings are shown in Figures 11 and 12. Plume opacities averaged very nearly 20% on each test day. Maximum opacities observed were 27.9% on Day 1 and 31.4% on Day 2. The readings were taken for a total 131 min on the first test day and 245 min on the second.

PCB AND PAH COMPOUNDS

A special sampling train, using a Florisil adsorbent trap, was used to collect two samples of both particulate and vaporous emissions. These were analyzed for PCB and PAH compounds using GC/MS techniques.

TABLE 30. SUMMARY OF BAHCO ASH ANALYSIS

Size range (μm)	Primary ash (% by wt.)	Secondary ash (% by wt.)
> 60	40	0.9
40-60	11	0.5
30-40	7.7	0.5
20-30	8.8	1.4
15-20	4.5	1.7
10-15	7.5	4.3
7.5-10	5.5	6.2
5.0-7.5	4.0	13.5
3.5-5.0	2.8	19.0
2.5-3.5	2.0	24.2
1.5-2.5	4.3	21.2
< 1.5	1.9	6.6

TABLE 31. SIMULATED PARTICLE SIZE DISTRIBUTIONS DEVELOPED BY UOP

Size range (μm)	Collector inlet (% by wt.)	Collector outlet (% by wt.)
> 60	35.48	0.02
40-60	9.75	0.01
30-40	6.82	-
20-30	7.79	-
15-20	3.93	-
10-15	6.69	0.01
8-10	4.01	0.08
6-8	3.32	0.27
4-6	3.73	1.39
2-4	7.22	12.17
< 2	11.26	86.05

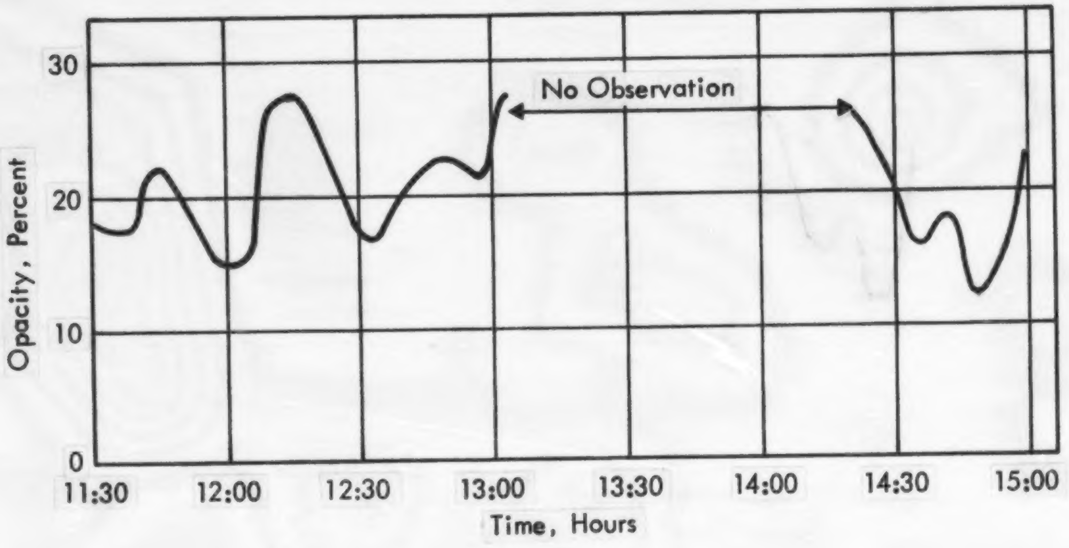


Figure 11. Plot of opacity versus time, 7/24/78.

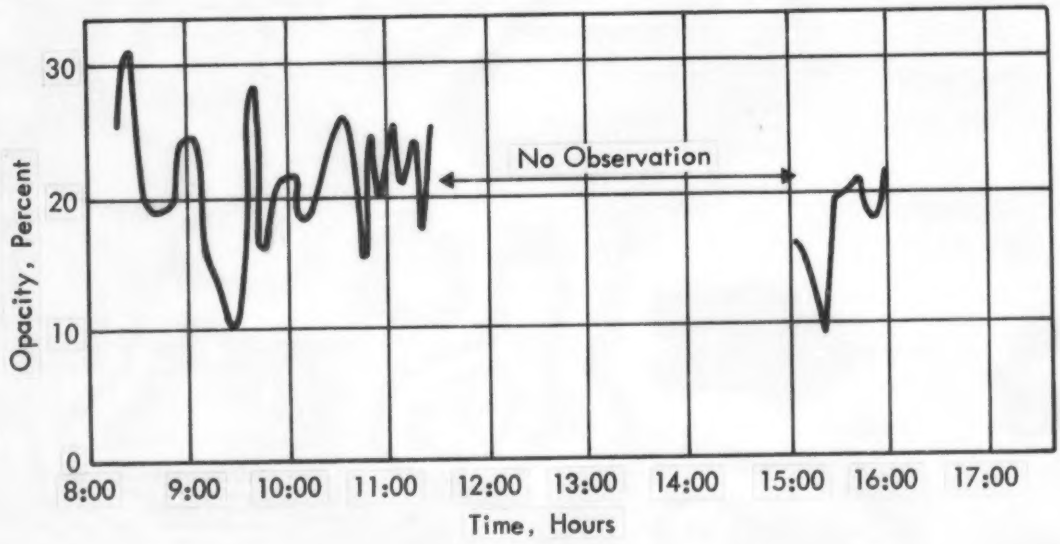


Figure 12. Plot of opacity versus time, 7/25/78.

Contents of the two impingers which preceeded the Florisil trap were analyzed, along with the Florisil adsorbent, for PCB materials. Preliminary screening using EC/GC indicated that most of the samples did not contain sufficient quantities of PCB materials to permit mass spectral verification. Using Arochlor 1254 and 1260 standards, a detection limit corresponding to a total of 1 μg of PCB per sample was obtained.

Only the Florisil trap from Run 1 and the second impinger solution from Run 2 were submitted for further analysis by GC/MS because of the complexity of their EC/GC chromatograms. A selective ion monitoring (SIM) technique, using an Arochlor 1254 standard, was employed. All sample responses were found to be less than 1 μg total PCB content for both samples.

Results from analysis of the Florisil train components for PAH compounds are shown in Table 32. In all the samples analyzed, no PAH materials were identified at levels which permitted structural confirmation by GC/MS. The possible compounds observed are therefore listed as "less than" the detection limit.

SASS - LEVEL 1 ASSESSMENT

In addition to the air emissions testing previously described, one sample was collected using the EPA-developed SASS in conjunction with EPA's Level 1 environmental assessment procedure. The SASS run was made near the end of the 2nd day of testing. Brief explanations of the operation of the train and the required analytical procedures are included in Appendices A and C of this report. Results are discussed in the subsections below.

Particulate Concentration

The high-volume SASS collects a particulate sample in a manner similar to EPA Method 5, except that the SASS probe is positioned at a single sampling point in the air stream for the entire period of sample collection. Therefore, the SASS sample can only serve as an approximation of the true particulate emission concentration.

Weights obtained for the various portions of the SASS sample are shown in Table 33. Sixty-five percent of the sampled particulate was collected by the 1 μm cyclone and the final filter, indicating a predominance of very fine particles in the stack emissions. Table 34 presents a summary of the particulate concentrations and emission rates corresponding to each portion of the SASS sample. Both metric and English units are included.

The total particulate concentration measured by the SASS was 0.0906 g/dscm (0.0396 gr/dscf). This compares very well to the concentration of 0.093 g/dscm (0.041 gr/dscf) which resulted from the third Method 5 sampling run (completed just prior to the SASS run). Particulate emission rates measured by the SASS, in terms of weight per unit time and weight per unit of heat input, are also shown in the table.

TABLE 32. ANALYSIS OF FLORISIL TRAIN COMPONENTS FOR PAH BY GC/MS

	Detection limit[a]	Run 1			Run 2[b]		
Gas volume (cu m)	0.060	0.061			0.059		
		µg/cu m					
Compound	µg/cu m	Florisil	Impinger 1	Impinger 2	Florisil	Impinger 1	Impinger 2
Acenaphthylene	37	-	-	-			
Fluorene	35	-	-	-			
Phenanthrene	16	< 16[d]	< 16[d]	-			
Anthracene	10	< 10[d]	-	-			
Fluoranthene	11	< 11[d]	-	-			
Pyrene	10	-	-	-			
Chrysene	33[c]	-	-	-			
1,2-Benzanthracene	32	-	-	-			
Benzo[a]pyrene	40[c]	-	-	-			
Perylene	37[c]	-	-	-			
Indeno[1,2,3-c,d]pyrene	100[c]	-	-	-			
1,2,5,6-Dibenzanthracene	150[c]	-	-	-			
1,12-Benzoperylene	90[c]	-	-	-			

[a] Based on the response of 1 µl of 1 ng/µl standard except where noted, assuming a gas volume sampled of 0.06 cu m and a 1,000 count minimum signal.

[b] Detectable signals for PAH compounds were not observed in samples from Run 2.

[c] Based on the response of 1 µl of 5 ng/µl standard.

[d] Low level signals which could not be verified by GC/MS.

TABLE 33. SASS PARTICULATE ANALYSIS (LEVEL 1)

Constituent	Front end rinse	10 µm Cyclone	3 µm Cyclone	1 µm Cyclone	Filter
Weight (g)	0.2588	0.1331	0.4441	0.7351	0.8080
CH_2Cl_2 extract			Combined		
TCO (mg)	0.017		0.28		
GRAV (mg)	4.3		2.2		
IR (qualitative identification)	a/		a/		
LC (F fractions)	b/		b/		

a/ Samples did not meet the Level 1 criteria for these analyses to be performed.

b/ IR absorptions of sufficient intensity to allow interpretation were not observed.

TABLE 34. SUMMARY OF SASS PARTICULATE RESULTS

	Particulate concentration		Particulate emission rate			
Sample fraction	g/dscm	gr/dscf	kg/hr	lb/hr	g/MJ	lb/10^6 Btu
Front end rinse	0.0099	0.0043	0.75	1.65	0.005	0.012
10 µm cyclone	0.0051	0.0022	0.38	0.84	0.003	0.006
3 µm cyclone	0.0169	0.0074	1.29	2.83	0.009	0.021
1 µm cyclone	0.0280	0.0122	2.12	4.67	0.015	0.034
Filter	0.0308	0.0134	2.33	5.13	0.016	0.037
Total	0.0906	0.0396	6.89	15.18	0.047	0.110

Inorganic Analysis

Under Level 1 protocol, each portion of the SASS sample is to be analyzed for elemental composition using SSMS. The SASS particulate fractions were not submitted for this analysis, however, since the Method 5 particulate samples (filters) were used instead to provide more representative information regarding elemental compositions.

SSMS analysis was only performed on the aqueous condensate from the condenser module and the first impinger contents from the final portion of the SASS. Results of the condensate analysis are shown in Table 35 in terms of an air concentration ($\mu g/m^3$). Sample volume through the SASS was approximately 925 dscm.

Many elements were not detected at the 0.8 μg lower limit (0.009 $\mu g/m^3$). Only a few elements were observed at air concentrations greater than 1 $\mu g/m^3$. These included Zn, Ni, Fe, Mn, Cr, Ca, K, Cl, S, P, Si, Mg, Na, and F. Iron and chromium were present at the highest concentrations (> 43 and 22 $\mu g/m^3$, respectively).

Table 36 summarizes results of the SSMS analysis of the SASS hydrogen peroxide impinger contents. Many elements were not detected or had air concentrations less than 1 $\mu g/m^3$. Pb, Mo, Mn, Ca, P, Si, and Na showed concentrations between 1 and 10 $\mu g/m^3$, while Zn, Cu, Ni, Fe, Cr, and S exceeded the upper range of the SSMS screening technique (> 13 $\mu g/m^3$). The data in Tables 35 and 36 indicate the relative magnitude of trace element emissions from the Burlington boiler in the vaporous phase.

It is important to note that concentrations of certain trace metals, particularly Fe, Cr, and Ni, in the aqueous condensate and impinger solution are probably greatly elevated due to corrosion of the stainless steel internal components of the SASS. Corrosion products have been verified in past MRI studies in which the SASS was used, (3,4) and the appearance of the sample solutions in this study indicates that some corrosion also occurred during the SASS run at Burlington Electric.

Organic Analysis

Additional analysis of the SASS particulate, as prescribed by the Level 1 procedures, included a methylene chloride extraction for subsequent qualitative and quantitative determination of organic compounds. The particulate extracts were analyzed for total chromatographable organics (TCO) and gravimetric residue (GRAV), with the resulting data shown in Table 33. In all concentrated extracts, numerous additional peaks were observed in the TCO analysis which were beyond a C-17 hydrocarbon retention time. Because the Level 1 protocol does not include peaks beyond C-17 for TCO calculation, these data are not reflected in the tabulated results (Table 33). Attempts to qualitatively assess the nature

TABLE 35. ELEMENTAL ANALYSIS OF SASS AQUEOUS CONDENSATE BY SSMS

Element	Concentration (µg/cu m)[a]	Element	Concentration (µg/cu m)[a]
Uranium	ND	Ruthenium	ND
Thorium	ND	Molybdenum	0.43
Bismuth	ND	Niobium	ND
Lead	< 0.03	Zirconium	≤ 0.011
Thallium	-	Yttrium	ND
Mercury	0.009[b]	Strontium	0.043
Gold	ND	Rubidium	ND
Platinum	ND	Bromine	0.22
Iridium	ND	Selenium	≤ 0.011
Osmium	ND	Arsenic	0.086
Rhenium	ND	Germanium	ND
Tungsten	ND	Gallium	ND
Tantalum	ND	Zinc	1.1
Hafnium	ND	Copper	0.32
Lutetium	ND	Nickel	8.6
Ytterbium	ND	Cobalt	0.22
Thulium	ND	Iron	> 43
Erbium	ND	Manganese	1.1
Holmium	ND	Chromium	22
Dysprosium	ND	Vanadium	0.043
Terbium	ND	Titanium	0.22
Gadolinium	ND	Scandium	≤ 0.002
Europium	ND	Calcium	11
Samarium	ND	Potassium	1.1
Neodymium	ND	Chlorine	5.4
Praseodymium	ND	Sulfur	11
Cerium	ND	Phosphorus	3.2
Lanthanum	ND	Silicon	1.1
Barium	0.043	Aluminum	0.43
Cesium	ND	Magnesium	1.1
Iodine	0.022	Sodium	2.2
Tellurium	ND	Fluorine	2.2
Antimony	ND	Oxygen	NR
Tin	ND	Nitrogen	NR
Indium	STD	Carbon	NR
Cadmium	ND	Boron	0.22
Silver	ND	Beryllium	ND
Palladium	ND	Lithium	0.002
Rhodium	ND	Hydrogen	NR

Note: STD = internal standard; NR = not reported; ND = not detected (< 0.009 µg/cu m).

[a] Detection limit = 8 µg, based on a collected volume of 400 ml.

[b] Flameless atomic absorption analysis.

TABLE 36. ELEMENTAL ANALYSIS OF SASS HYDROGEN PEROXIDE IMPINGER COUNTER BY SSMS

Element	Concentration (μg/cu m)	Element	Concentration (μg/cu m)
Uranium	ND	Ruthenium	ND
Thorium	ND	Molybdenum	1.1
Bismuth	ND	Niobium	0.029
Lead	1.6	Zirconium	0.003
Thallium	ND	Yttrium	ND
Mercury	3[a]	Strontium	0.046
Gold	ND	Rubidium	ND
Platinum	ND	Bromine	0.029
Iridium	ND	Selenium	0.12
Osmium	ND	Arsenic	0.12
Rhenium	ND	Germanium	B
Tungsten	ND	Gallium	0.11
Tantalum	ND	Zinc	> 16
Hafnium	ND	Copper	> 16
Lutetium	ND	Nickel	> 16
Ytterbium	ND	Cobalt	0.66
Thulium	ND	Iron	> 16
Erbium	ND	Manganese	4.3
Holmium	ND	Chromium	> 16
Dysprosium	ND	Vanadium	0.065
Terbium	ND	Titanium	0.29
Gadolinium	ND	Scandium	ND
Europium	ND	Calcium	8.2
Samarium	ND	Potassium	0.32
Neodymium	ND	Chlorine	0.043
Praseodymium	ND	Sulfur	> 13
Cerium	ND	Phosphorus	3.0
Lanthanum	ND	Silicon	9.1
Barium	0.008	Aluminum	0.12
Cesium	ND	Magnesium	0.26
Iodine	ND	Sodium	2.8
Tellurium	ND	Fluorine	B
Antimony	0.003	Oxygen	NR
Tin	0.16	Carbon	NR
Indium	ND	Boron	0.10
Cadmium	0.013	Beryllium	ND
Silver	0.029	Lithium	0.009
Palladium	ND	Hydrogen	NR
Rhodium	ND		

Note: B = background levels equal or exceed sample levels; STD = internal standard; NR = not reported; ND = not detected (< 0.003 μg/cu m).

[a] Flameless atomic absorption analysis.

of the TCO/GRAV components through infrared (IR) analysis were not successful since IR absorptions of intensity sufficient to allow interpretation were not observed.

Further organic analysis of the particulate extracts via LC fractionation was not carried out since the combined TCO and GRAV values were below the 15 mg minimum requirement which is stipulated in the Level 1 procedures.

The organic module which follows the particulate filter in the SASS serves to trap gaseous organic constituents in the sample stream using XAD-2 resin adsorbent. After sample collection, both the resin itself and the rinse of the internal surfaces of the organic module are collected for analysis. In addition, the aqueous condensate from the organic module is also collected and analyzed (the sample air stream is quickly cooled just prior to the XAD-2 resin cartridge to allow optimum adsorption). Results of the TCO/GRAV analyses for these sample fractions are shown in Table 37. Direct interpretation of these data is difficult. However, one method of assessment is the use of EPA's SAM-1A, which is presented in Section 5 of this report.

TABLE 37. LEVEL 1 ORGANIC ANALYTICAL RESULTS

Sample fraction	TCO (mg)[a,b]	GRAV (mg)[b]
XAD-2 resin	5.9[c]	34[d]
Organic module rinse	0.087	2.0
Aqueous condensate	0.29	[e]

[a] Sample values corrected for reagent blanks.

[b] Based on analysis of concentrated sample extracts.

[c] Corrected for XAD-2 resin background contributions.

[d] Determined from the unconcentrated sample. No background level was observed in the unconcentrated blank.

[e] Not detected.

IR spectra obtained from analysis of the GRAV residues produced interpretable data only for the concentrated XAD-2 resin extract. These data are shown in Table 38 and indicate absorbance peaks primarily characteristic of carbonyl-containing hydrocarbon materials.

Only the organic content of the XAD-2 sample was above the minimum requirement for further analysis (15 mg) and therefore the extract was fractionated by the LC method. Resulting TCO and GRAV values are shown in Table 39. These analyses revealed that the bulk of the organic material was concentrated in the more polar LC6 and LC7 fractions. The TCO analysis also indicated the presence of organic material in fraction LC3.

The LC fractions 6 and 7 were the only ones to produce interpretable spectra from IR analysis. The observable absorbance peaks and their functional group assignments are presented in Table 40. The most prominent feature consists of a carbonyl band in the 1700 cm^{-1} region. Additional peaks of lesser intensity corresponding to aliphatic, aromatic, and possibly hydroxyl materials were observed. Distinctions between classes of acids, aldehydes, esters, and ketones were not possible due to the limited data; however, the presence of acids or esters appears most likely based on the LC fractionation scheme. Acids and esters have been reported to elute in LC fractions 6 or 7, in contrast to aldehydes and ketones which reportedly elute in LC fraction 4. Although a strong absorption suggesting O-H stretching (3400 to 3550 cm^{-1}) was observed in the unfractionated XAD-2 extract, which may be indicative of a carboxylic acid or an alcohol, the absence of a similar absorbance in the IR data for the LC fractions would suggest that the prevalent functional group is an ester. The large absorbance observed in the unfractionated sample may be due to the presence of water in either the sample extract or the salt plates used for the IR analysis. Since the XAD-2 resin was found to be wet after sampling, the presence of water at its solubility limit in the initial sample extracts would not be unlikely. The IR spectra were found to be essentially the same for both the concentrated XAD-2 extract and the LC fractions. Of the two LC fractions, LC6 was found to produce the more intense spectra. Interpretation of IR spectra of other concentrated sample extracts was not generally possible due to the low concentrations of organic materials present and the resultant absence of observable absorptions above background levels. IR spectra for the remaining LC fractions were not taken due to the absence of measurable organic material as identified in the gravimetric analyses of those fractions.

The final phase of the organic analysis of the XAD-2 resin extract consisted of direct inlet LRMS. Thermograms and ion range plots were constructed to identify scanning regions of interest. Then spectra from each selected scan range were obtained. A complex mixture of ions was observed for each range of interest, which was further complicated by high background levels of the less volatile components. Because of these problems, detailed interpretation of the LRMS data was not performed.

TABLE 38. IR SPECTRAL ANALYSIS OF CONCENTRATED XAD-2 RESIN EXTRACT

Frequency ν (cm^{-1})	Intensity[a]	Functional group assignment
1460	M	C-H bending, O-H bending
1600-1650	S	C=O stretching
2850	M	C-H stretching
2920	S	C-H stretching
2960	W	C-H stretching
3400-3550	S	O-H stretching (broad)

a/ S = strong, < 85% T; M = medium, 85 to 95% T; W = weak, > 95% T.

TABLE 39. LEVEL 1 ORGANIC ANALYSIS OF LIQUID CHROMATOGRAPHIC FRACTIONS OF XAD-2 RESIN SAMPLE

LC Fraction	TCO[a] (mg)	Gravimetric (mg)
1	0.10	-[b]
2	0.0055	-
3	1.1	-
4	0.010	-
5	-	-
6	0.80	6.8
7	0.44	6.4

a/ Sample values corrected for reagent blank contributions.

b/ Blanks denote insufficient material to be detected.

TABLE 40. IR SPECTRAL ANALYSIS OF LC FRACTIONS 6 AND 7

LC Fraction	Frequency ν (cm^{-1})	Intensity[a]	Functional group assignment
6	1130	W	Unassigned
	1290	M	C-O stretching
	1460	W	C-H bending
	1710-1740	S	C=O stretching
	2870	M	C-H stretching
	2940	S	C-H stretching
	2970	W	C-H stretching
7	1070-1140	W	Unassigned
	1230-1300	M	C-O stretching
	1390-1420	W	Unassigned
	1550-1600	W	Unassigned
	1690-1720	S	C=O stretching
	2850	M	C-H stretching
	2920	S	C-H stretching
	2950	W	C-H stretching

[a] S = strong, < 85% T; M = medium, 85 to 95% T; W = weak, > 95% T.

ELECTRON SPECTROSCOPY FOR CHEMICAL ANALYSIS

Elemental analysis of particulate samples from the Burlington Electric test program was conducted to obtain information on potential hazards. However, elemental analysis conducted using SSMS only indicates the total elemental composition and does not differentiate between surface and internal concentrations. Moreover, SSMS does not offer any potential information about the specific chemical species contained in the particulate material, which is very important for establishing the hazard potential. Therefore, particulate samples from the Burlington process were analyzed by ESCA to identify any hazardous elements present at surface concentrations greater than 0.5%. Selected elements detected were then speciated to determine the oxidation state and the chemical form of the element as it exists on the surface of the solid. Auger analysis was also performed to achieve improved sensitivity for certain elements.

Samples of particulate from each cyclone and the filter from the SASS train, primary and secondary collector ash, and bottom ash were submitted for analysis. The 1 μm cyclone catch from the SASS train was analyzed first to estimate the amount of information that could be found from stack particulates. The 1 μm particulate had the greatest available surface area of the SASS particulate samples and therefore offered the greatest potential for detection and speciation using ESCA. However, few elements of interest were detectable in the 1-μm particulate fraction. Therefore, the rest of the SASS train samples and the collector ash samples were not analyzed. Bottom ash elemental composition, however, was expected to be different from the stack particulates and was therefore analyzed.

ESCA and Auger analysis were performed by Physical Electronics Industry using a Model 550 series instrument built by the same company. An ESCA survey scan was made of each sample and peaks were identified by element and electron transition type. General composition elements such as carbon, oxygen, calcium, sodium, potassium, aluminum, and silicon were noted but were not of interest with respect to characterization of hazardous elements present in the samples. No transition metals (except iron) or heavy metals were identified in the survey scan. Sulfur and fluorine were detected in the SASS 1 μm particulate survey scan and selected for high resolution analysis to determine their chemical types. The SSMS results for collector ash and bottom ash were used to select additional elements with concentrations greater than 250 ppm for the 1-μm particulate and bottom ash samples, respectively. The elements were searched in the samples by repetitive energy scans to enhance the signal. The energy region of the most intense emission ($\pm$ 10 ev) was repeatedly scanned and the signal averaged to increase the detection limit. Although 250 ppm is well below the $\sim$0.5% detection limit for ESCA, if any of these selected elements were enriched on the particulate surface, the surface concentration could be 10 to 50 times higher than the bulk concentration and therefore should be potentially detectable by ESCA.

Table 41 summarizes the results from the survey scan (atom percent) and high resolution scans for the 1-μm particulate. Carbon 1s binding energy is used as a reference to compensate for sample charging which shifts binding energy. In addition to the general composition elements, fluorine, sulfur and titanium were detected. The fluorine species is rather surprising because fluoride salts were expected. However, the observed fluorine binding energy precludes the presence of fluoride salts and suggests the presence of carbon-fluorine bonding. The presence of carbon-fluorine bonds suggests the presence of reactive fluorine species in the stack which react with carbon on the particulate surface. Table 42 summarizes the results from the survey scan (atom percent) and high resolution scans for the bottom ash.

TABLE 41. ESCA RESULTS FOR 1-μ PARTICULATE

Element	Atom (%)	Corrected binding energy (ev)	Orbit	Chemical species	Comments
Oxygen	41	532	1s	a/	
Carbon	37	285	1s	a/	
Silicon	7	100	2p	a/	
Aluminum	5	118	2s	a/	
Potassium	4	297	2p	a/	
Sulfur	4	170[b]	2p	$SO_4^=$	
Fluoride	1	687[b]	1s	C-F	Organically bound fluorine
Titanium	Trace	458[b]	2p	TiO_2	
Arsenic	ND	46	1s	c/	
Manganese	ND	642	2p	c/	
Vanadium	ND	517	2p	c/	
Chromium	ND	575	2p	c/	
Nickel	ND	855	2p	c/	
Barium	ND	781	3d	c/	

a/ Species for major composition elements not determined.

b/ Data from high resolution analysis.

c/ Element could not be detected.

Because few elements of interest were detected by ESCA, the 1-μm particulate was analyzed by Auger techniques. Auger is more sensitive than ESCA for certain elements and the detection of selected elements was attempted. Figure 13 is the survey scan of the 1 μ particulate sample. Magnesium was the only additional element detected. Fluoride was not observed in the Auger analysis when compared to the ESCA results. This is probably due to the decreased sensitivity of Auger analysis to fluoride species.

TABLE 42. ESCA RESULTS FOR BOTTOM ASH

Element	Atom (%)	Corrected binding energy (ev)	Orbit	Chemical species	Comments
Carbon	45	285	1s	a/	
Oxygen	34	532	1s	a/	
Silicon	12	100	2p	a/	
Aluminum	9	118	2s	a/	
Calcium	Trace	350	2p	a/	
Iron	Trace	710	2p	a/	
Titanium	Trace	458c/	2p	TiO_2	
Manganese	Trace	642c/	2p	MnO_2	Other possible compounds MnO and MnX_2
Chromium	b/	575	2p	b/	
Zirconium	b/	182	3d	b/	
Strontium	b/	134	3d	b/	
Vanadium	b/	517	2p	b/	

a/ Species for major composition elements not determined.

b/ Element could not be detected.

c/ Data from high resolution analysis.

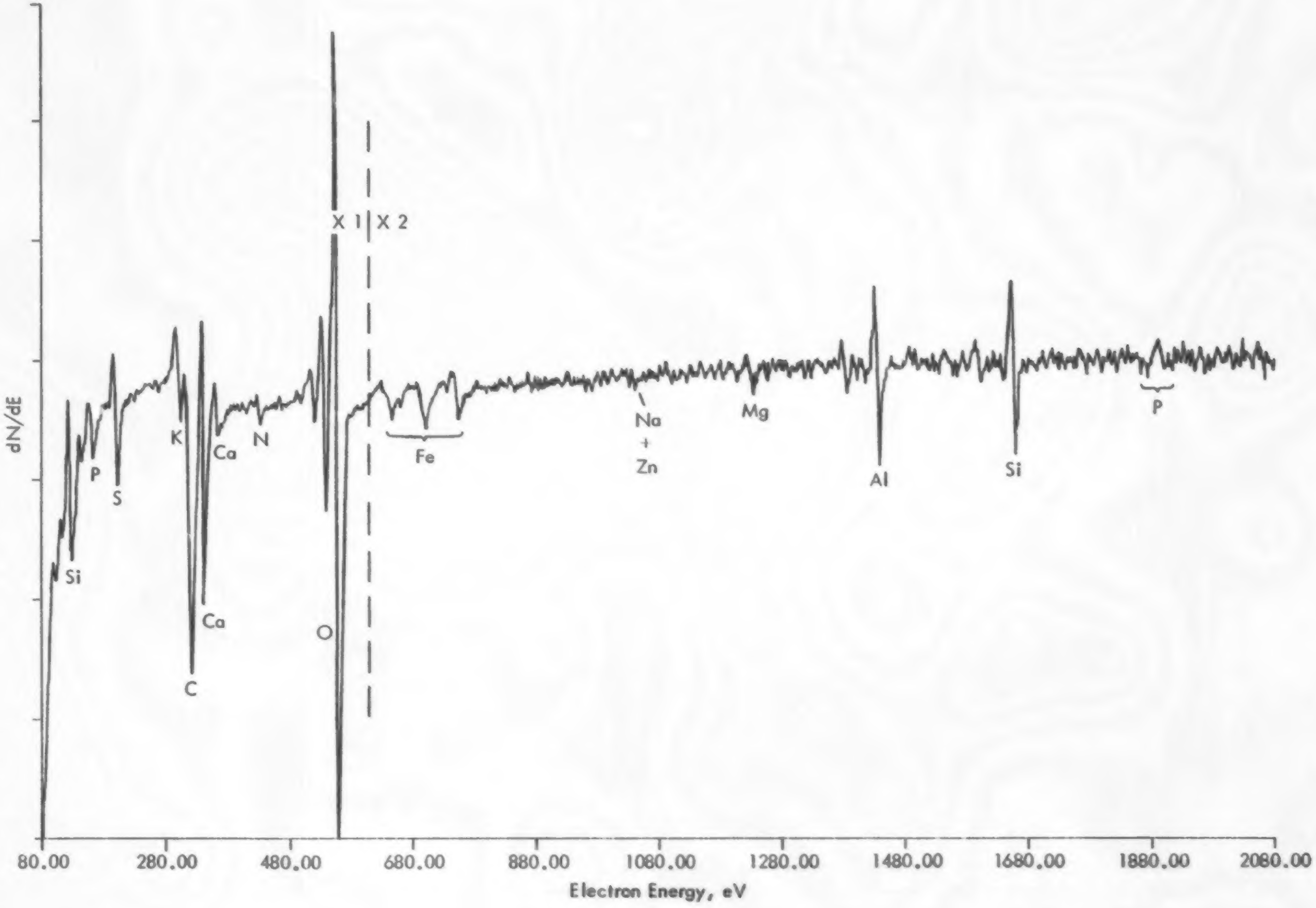


Figure 13. Auger survey scan of 1-μ particulate.

SECTION 5

ENVIRONMENTAL ASSESSMENT OF BURLINGTON DATA BASED ON EPA'S SAM-1A

APPROACH

The environmental assessment data obtained from MRI's study of the Burlington power plant provides a good deal of quantitative and semiquantitative information about pollutants in the air, water, and solid waste streams resulting from thermal processing of refuse. To ascertain the significance of these data and thereby determine the need for control of any particular pollutants that may be of concern, a comparative set of emission criteria is needed. Although some emission level goals have been established in the form of EPA's New Source Performance Standards and Effluent Guidelines and Standards, these regulations are source-specific and extrapolation to other types of processes may not be valid. There are also many pollutant species, such as many forms of hydrocarbons, certain pesticides, trace metals, etc., for which emission limitations have never been promulgated.

Therefore, a standardized data evaluation methodology recently developed by EPA's Industrial Environmental Research Laboratory - Research Triangle Park/Energy Assessment and Control Division (IERL-RTP/EACD) was employed to interpret the Burlington test results. The IERL-RTP/EACD evaluation scheme consists of using a data calculation procedure known as SAM-1A to compare effluent stream contaminant levels to Multimedia Environmental Goals (MEGs), which are also being developed by IERL-RTP. MEGs are guideline limitations for contaminants that are judged to be: (a) appropriate for preventing certain negative effects in the surrounding populations or ecosystems (ambient air, water, or land); or (b) representative of the control limits achievable through application of the best available technology. These emission level goals are approximated using: (a) ambient concentration goals which are based on hazards posed to public health and welfare as a result of long-term or continuous exposure to emissions; (b) natural background levels which can be used as ultimate goals for the elimination of discharges; and (c) hazards to human health or to ecology from short-term exposure to emissions. Those MEGs derived from short-term exposure data are known as MATE values and are intended to serve both as relative hazard indicators and very approximate emission guidelines. Pollutants emitted at levels lower than these guidelines are not expected to evoke significant harmful or irreversible responses from exposures of less than 8 hr duration.

For each of the three environmental media (air, water, and land), there are two sets of MATE values. The first, designated as health-based MATEs, is based on evidence of acute and chronic effects on humans and also on studies of animal toxicity. The ecology-based MATEs are derived from studies of pollutant effects on plant and aquatic life.

MATE values, therefore, can be a very useful tool by revealing potential environmental hazards in source assessment data. The SAM technique does not work in all cases, however, since there are many contaminants for which MATEs have not yet been established.

The SAM is basically a screening technique designed to provide a quantitative means of assessing the pollution potential of a process or source. The SAM format focuses on each separate effluent stream, whether it evolves from the process itself or associated pollution control equipment. The information resulting from the SAM procedure can provide the guidance required to progress from a Level 1 to a Level 2 source analysis program, where specific chemical compounds are targeted for study.

In the most basic version of SAM (designated as SAM-1A), which was used to evaluate the data in this report, the emitted contaminants are assumed to be noninteractive with the ambient environment (i.e., effluent components are released without transformation and are not involved in synergistic activities). Also, no assumption is made about the dispersion modes of individual pollutants to their receptor sites, except that such dispersion would have at least the equivalent effect of the safety factors which are normally applied when converting short-term exposure data to estimates of longer term chronic ambient exposure levels.

The SAM-1A approach compares each sample fraction or specific pollutant concentration in a given effluent stream to a corresponding MATE value. The ratio of these quantities is known as the degree of hazard (H) for that particular pollutant. Any contaminant whose H value is greater than unity is flagged as a potential problem pollutant. The product of a contaminant's H value and the effluent stream flow rate establishes that contaminant's Toxic Unit Discharge Rate (TUDR). The H values and TUDRs are then summed for each effluent stream. This derived information can subsequently be used to rank effluent streams on the basis of the magnitude of their TUDRs, establish pollutant priorities and identify problem pollutants, and determine the need for control/disposal technology development.

BURLINGTON DATA

The Burlington Electric power boiler system has four major effluent streams that were monitored for this study. They included: (a) bottom ash discharged from the traveling stoker grate; (b) collected fly ash from the primary mechanical collector; (c) collected fly ash from the secondary mechanical collector; and (d) exhaust gas emissions. The constituents of each effluent stream, as measured by MRI and discussed in the previous section, were compared to their corresponding MATE values via the SAM-1A procedure. Subsequently, the H and TUDR values were calculated for each stream as shown in Table 43. The data which were used for these compilations appear in the tables in Appendix D.

TABLE 43. SUMMARY OF SAM-1A EFFLUENT ANALYSIS

	Health-based	Ecological-based
Degree of hazard		
Bottom ash	4,400	1,020,000
Primary collector ash	2,100	1,020,000
Secondary collector ash	7,000	1,070,000
Stack emissions	180	16
Toxic Unit Discharge Rate		
Bottom ash (g/sec)	110,000	25,600,000
Primary collector ash (g/sec)	115,000	56,900,000
Secondary collector ash (g/sec)	11,000	1,700,000
Stack emissions (cu m/sec)	3,800	330

Results of the SAM-1A analysis show the secondary collector ash to have the highest health-based and ecological-based degrees of hazard. However, the degrees of hazard (health) for the other two ash streams (bottom ash and primary collector ash) are of the same order of magnitude as the value for the secondary ash, and the degrees of hazard (ecological) are also very similar for all three ash streams. The boiler air emissions showed low degrees of hazard in comparison to the other effluents.

Because the primary collector ash has the highest material discharge rate of the three ash effluent streams, it yielded the largest TUDR value. TUDRs calculated for the bottom ash stream were just slightly less than the primary ash values.

When assessing the data in Table 43, it must be noted that the summations shown include some "less than" and "greater than" values which add a factor of inaccuracy to the cumulative totals. For lack of a better strategy, absolute values were used in computing the H and TUDR values presented in the table (see the SAM-1A data sheets in Appendix D).

The high degrees of hazard (health based) associated with each of the ash streams are primarily the result of high sample concentrations/low MATE concentrations for a few trace metals. H values for the metals Li, Be, Cr, Mn, Fe, and Ni in the bottom ash, for example, contributed 4,090 to the total stream degree of hazard of 4,400. Likewise, the very large ecological-based degree of hazard for the bottom ash stream (1,020,000) is predominantly the result of the high H value for the element phosphorus (1,000,000). An additional 15,300 of the 1,020,000 total is due to the elements Li, Ba, Al, V, Cr, Mn, Fe, Ni, Cu, and Cd. Similar patterns are evident from analysis of the data generated for the two collector ash streams. Generally, the same elements were responsible for the high degrees of hazard in both cases.

The results of the SAM-1A analysis described above may not reflect the true hazard potential of the ash streams because of the physical nature of the ash. For example, the bottom ash is discharged as agglomerated chunks of varying size. The MATE concentrations used in the SAM-1A procedure are based on the potentially hazardous effects of each element or compound. No provision appears in the methodology to relate the amount of a particular element measured in the bottom ash to what may actually be released into the environment. It is possible that much of the element may never be leached from the pieces of ash material. Therefore, the degree of hazard, as determined by SAM-1A, could be very overestimated.

Since TUDRs are the product of H values and the effluent stream discharge rate, it follows that the primary collector ash would have the highest TUDR values. Health- and ecological-based TUDRs for the bottom ash stream were only slightly lower, while secondary collector ash TUDRs were at least an order of magnitude less than the primary collector ash values. A combination of low degrees of hazard and a moderate effluent flow rate yielded TUDR values for the stack emissions which were lowest among the four effluent streams.

The health-based degree of hazard determined for the stack emissions (180) is mainly the result of high H values for CO, SO_2, NO_x, and several trace metals, namely As, Ni, and Cr, plus one group of organic components (the LC3 fraction from the SASS organic sample). It is possible, however, that the high Ni and Cr concentrations could have resulted from corrosion of some stainless steel components within the SASS and do not accurately reflect the levels of these metals in the boiler exhaust gases. Also, the designated MATE concentration for SASS organic fraction LC3 (0.02 $\mu g/m^3$) is a "worst case" assumption based on the hazard potential of benzo[a]pyrene, since the exact composition of LC3 is unknown. PAH analysis of the SASS organic sample did not indicate the presence of benzo[a]pyrene. Therefore, it is certain that the H (health) value for the LC3 fraction of the sample is suspect. This case points out a deficiency in the EPA SAM-1A methodology.

The ecological-based degree of hazard is very low for the stack emissions because only a few ecological-based MATE concentrations have been established for airborne emissions.

The degree of hazard values obtained for SO_2 and NO_x also point out the conservative nature of some MATE concentrations. When viewed on a parts per million basis, these gaseous constituents appear to be of little concern because of their relatively low levels. The SAM-1A analysis, however, shows them as warranting concern since their degrees of hazard are greater than one.

Although many of the constituents analyzed in each of the effluent streams had H values greater than unity, many others had very low degrees of hazard. Therefore, the SAM-1A analysis methodology at least provides a means for identifying those pollutants which may or may not be of environmental concern. It allows an initial analysis of environmental assessment data that would otherwise not be available.

SECTION 6

CONCLUSIONS

Summarized below are the major findings of the Burlington Electric wood and oil fired boiler environmental assessment. They are presented according to each of the effluent streams and the SAM-1A results.

BOTTOM ASH

- Elemental analysis of the bottom ash residue yielded a number of elements at concentrations greater than 1,000 μg/g. These included Ba, Fe, Mn, Ti, Ca, K, S, P, Si, Al, Mg, and Na. Ba, Zr, Sr, and Li exhibited the largest increases relative to their concentrations in the wood and oil fuels.

- PCB analysis did not reveal the presence of any PCB materials in the bottom ash at a detection level of 0.05 μg/g.

- Phenanthrene was the only PAH compound which could be confirmed as a constituent of the bottom ash. The highest level of phenanthrene detected was 1.7 μg/g.

PRIMARY COLLECTOR ASH

- Major elemental components (> 1,000 μg/g) of the fly ash captured by the primary mechanical collector were Fe, Ti, Ca, K, S, P, Si, Al, Mg, and Na.

- No PCB materials were detected in the primary collector ash.

- No measurable levels of PAH compounds were found in any of the primary ash samples.

SECONDARY COLLECTOR ASH

- The same elements found in the bottom ash and primary collector ash at concentrations greater than 1,000 µg/g were also present at these levels in the secondary collector ash, with the addition of Sr and F. Elements in the range of 100 to 1,000 µg/g included Ce, Zr, As, Ga, Cu, Ni, Cr, V, Cl, and B.

- A trend was observed for the elements Hg, Br, Se, As, Cl, F, and B. Each showed progressively greater concentrations from the bottom ash through to the secondary collector ash, which suggests a fine particle/condensation phenomena.

- No positive signals for PCB materials were observed at the 0.05 µg/g detection level.

- Several PAH compounds, however, were identified in the secondary collector ash, namely acenaphthylene, phenanthrene, fluoranthrene, and pyrene. Concentrations ranged from 0.3 to 10 µg/g.

STACK EMISSIONS

- Concentrations of the gaseous criteria pollutants, SO_2, NO_x, and CO were low. Total hydrocarbon emissions were minimal.

- Intermittent elevated CO readings (up to 400 ppm) can probably be reduced by more consistent combustion conditions.

- The SO_2 levels observed would have been lower had the wood fuel not contained a small amount of coal fines as a result of adjacent storage piles.

- Total particulate emissions averaged only 0.18 g/dscm (0.08 gr/dscf). On a heat input basis, the emissions averaged 0.09 g/MJ (0.17 lb/10^6 Btu).

- The dual mechanical collection system had an average particulate removal efficiency of 95%.

- PCB materials could not be detected in the stack gases.

- Likewise, the presence of any PAH compounds in the air effluent could not be confirmed.

SAM-1A EFFLUENT ANALYSIS

- Assessment of the four effluent streams using the SAM-1A methodology showed that the secondary collector ash contained the highest degree of hazard, while the primary collector ash, because of its greater stream discharge rate, had the largest TUDR. The stack emissions had both the lowest stream degree of hazard and the lowest TUDR.

- High TUDRs for all three of the ash streams were primarily due to low MATE concentrations and relatively high measured concentrations of phosphorus and several trace metals. The calculated degree of hazard and TUDR values for these streams may give an unrealistically high appraisal of their actual hazard potential, since the physical form of the effluents and their disposal method is not fully considered under the SAM-1A approach. For solid waste streams, other factors, such as leachability, should be considered to determine which pollutants have the highest potential of being released to the environment.

REFERENCES

1. Riegel, S. A., and K. P. Ananth. Stationary Source Testing at Power Plant of University of Missouri at Rolla. EPA Contract No. 68-02-2166. MRI Draft Final Report. July 1977.

2. Golembiewski, M. A., and K. P. Ananth. Evaluation of Fabric Filter Performance at Browning Ferris Industries/Raytheon Service Company Resource Recovery Plant - Houston, Texas. EPA Contract No. 68-02-2166. MRI Draft Report. September 1977.

3. Gorman, P., M. Marcus, K. Ananth, and M. Golembiewski. Environmental Assessment of Waste-to-Energy Process: Union Carbide Purox® System. EPA Contract No. 68-02-2166. MRI Revised Final Report. April 1979.

4. Golembiewski, M. K. Ananth, G. Trischan, and E. Baladi. Environmental Assessment of a Waste-to-Energy Process: Braintree Municipal Incinerator. EPA Contract No. 68-02-2166. MRI Revised Final Report. April 1979.

5. Sanborn, C. R. Evaluation of Wood-Fired Boilers and Wide-Bodied Cyclones in the State of Vermont. Prepared for U.S. EPA Region I and Vermont Agency of Environmental Conservation. March 1, 1979.

APPENDIX A

ANALYTICAL METHODOLOGY

PROXIMATE ANALYSIS

Samples

One wood and one fuel oil sample for each of two test days were submitted for proximate analysis. A blind duplicate of each sample type was also analyzed.

Sample Preparation

Three 5-liter samples of wood were taken for each test day and mixed to produce a 1 liter composite sample. The samples were weighed as received and dried at 5°C above ambient temperature until a constant weight was obtained. The total sample was then ground until it passed a No. 60 sieve. A 1-liter sample of No. 2 fuel oil was taken for each test day and analyzed directly.

Sample Analysis

The ASTM procedure for coal was used for the analysis of both wood and fuel oil. The method, ASTM Method D-3172, includes: moisture determination according to Method D-3173; ash according to Method D-3174; volatile matter according to Method D-3175; and fixed carbon by difference. Heat of combustion was also determined using a calorimeter according to ASTM Method D-271. Additionally, oil density was determined by pycnometer. All of these analyses were performed by Industrial Testing Laboratory, Kansas City, Missouri.

Quality Assurance

Analytical precision was monitored by submitting blind duplicate samples of ground wood and fuel oil for one test run of the analytical subcontractor.

The data for duplicate analyses for both proximate and ultimate analyses are presented in Table A-1. All results are within ± 5% of the averaged values for duplicate tests with the exception of sulfur content. The high sulfur variability may be due to sample inhomogeneity and/or the relatively low sulfur content of the materials which were analyzed. Additionally, the wood samples

TABLE A-1. PROXIMATE AND ULTIMATE BLIND DUPLICATE ANALYSES OF WOOD AND FUEL OIL

	Wood			Fuel oil		
Analysis	Run 2A	Run 2B	Relative deviation (± %)	Run 2A	Run 2B	Relative deviation (± %)
As received:						
Moisture (%)	2.53	2.74	4	-	-	-
Ash (%)	3.70	4.12	5	< 0.001	< 0.001	-
Volatile matter (%)	68.35	68.72	< 1	-	-	-
Fixed carbon (%)	25.42	24.42	2	-	-	-
Sulfur (%)	0.34	0.72	36	0.23	0.36	22
Heat of combustion (Btu/lb)	9,253	9,266	< 1	19,525	19,501	< 1
Density (lb/gal)	-	-	-	7,056	7,054	< 1
Dry basis:						
Ash (%)	3.80	4.24	5	-	-	-
Volatile matter (%)	70.12	70.65	< 1	-	-	-
Fixed carbon (%)	26.08	25.11	2	-	-	-
Sulfur (%)	0.35	0.74	36	-	-	-
Heat of combustion	9,492	9,527	< 1	-	-	-
Hydrogen (%)	5.78	5.81	< 1	11.98	11.38	3
Carbon (%)	54.11	54.38	< 1	78.45	81.84	2
Nitrogen (%)	0.26	0.29	5	0.00	0.01	50
Oxygen (%)	35.74	34.59	2	9.34	6.63	17

were observed to contain coal powder which was introduced by the boiler feed system and could significantly influence the low level analyses, especially if the coal were not homogeneously dispersed. Losses of sulfur-containing fuel oil components during sample handling may also be a source of error in the analysis of fuel oil for sulfur.

Problems

The main problems encountered in this analysis were those of obtaining a representative sample of wood and in measurement of the lower concentration components such as sulfur.

ULTIMATE ANALYSIS

Samples

Ultimate analysis was performed on one wood and one fuel oil sample for each of two test days; a blind duplicate of each sample type for one test day was also analyzed.

Sample Preparation

The sample preparation for ultimate analysis was identical to that used for proximate analysis.

Sample Analysis

The ASTM method for coal was used for the analysis of wood and fuel oil. The method, ASTM Method D-3176, includes: determination of carbon and hydrogen according to Method D-3178; sulfur determination according to Method D-3177; nitrogen determination according to Method D-3179; ash is determined using the same methods as in proximate analysis; and oxygen is determined by difference.

Quality Assurance

Analytical precision was monitored by submitting blind duplicates of wood and fuel oil for one test run. The quality assurance data are included with the proximate testing quality assurance data listed in Table A-1. All results are within ± 5% of the averaged values for duplicate tests with the exception of analysis for nitrogen and oxygen in fuel oil. Variability in the nitrogen and oxygen analyses may be due to either loss of volatile nitrogen- or oxygen-containing compounds or air entrainment in the samples as analyzed. Since oxygen is determined by difference and is at a relatively low level, variations in other analytical results also will influence the quantity reported and appears to be the most probable source of variation. The extremely low quantity of nitrogen reported approaches detection limit levels, resulting in large percent deviations for extremely small amounts of material.

Problems

The main problems encountered in these analyses involved representative sampling and lack of analytical reproducibility at low concentrations.

PARTICULATE WEIGHT

Samples

Particulate weights were determined for the probe rinse, cyclone, filter, ether/chloroform extract residue, and water residue from the collector inlet Method 5 trains; the probe rinse, filter, ether/chloroform extract residue, and water residue from the collector outlet Method 5 trains; and the front half rinse, cyclones, and filter from the SASS train. Laboratory and field blanks were also included in the analyses. These blanks include: filters, solvents used for rinsing and sample extraction, and water used to fill the impingers.

Sample Preparation

Gelman Type A/E (fiberglass) filters for the Method 5 and SASS trains were dessicated prior to subsequent taring in a controlled humidity environment. Reweighings under comparable conditions were performed to determine the weight of particulate on the filters.

Acetone was used to rinse the probes of the Method 5 trains. The rinse from the front half of the filter holder was included in the probe rinse. These rinses were evaporated as separate samples and included as part of the front half weight. For the SASS train, methylene chloride was used to rinse the probe, cyclones, cyclone connecting lines, and front half of the filter holder. The rinses were combined and weighed as a single sample according to Level 1 protocol.2/ Cyclone catches were dessicated and weighed in a controlled humidity environment.

Liquid samples were transferred to previously dessicated and tared beakers and evaporated to dryness. Liquid samples were analyzed for organic material by extraction with three 25-ml portions of chloroform followed by extraction with three 25-ml portions of ethyl ether.1/ The chloroform and ether extracts were combined in previously dessicated and tared beakers. The extracts were evaporated to dryness under a stream of prepurified nitrogen. After extraction the water samples were poured into similarly treated beakers and evaporated to dryness on a steam bath.

Sample Analysis

Particulates, and dried samples, in beakers, were dessicated overnight, equilibrated at controlled temperature and humidity for 3 hr, and weighed to the nearest 0.1 mg on an analytical balance. Filters were dessicated to a constant weight.

Quality Assurance

Field blanks of filters, methylene chloride, acetone, and water were prepared with the samples. Laboratory blanks consisting of chloroform/ether and control beakers were also prepared and weighed at the same time as the samples. The tare weights and final weights of the filters were made under controlled humidity and temperature conditions. The balance was calibrated daily using a set of Class S reference weights. Multiple weighings of dried sample materials to constant weight were performed to assure accurate weight determinations.

Problems

No specific problems were encountered in these analyses.

References

1. Federal Register. Vol. 36, No. 159. Tuesday, August 17, 1971.

2. IERL-RTP. Procedures manual: Level 1 environmental assessment. EPA-60012-76-160a, June 1976.

ELEMENTAL COMPOSITION

Samples

All input and outlet streams were analyzed by SSMS for elemental composition. Samples of wood, fuel oil, bottom ash, primary collector ash, secondary collector ash, primary collector inlet particulate and secondary collector outlet particulate were analyzed for each test day. Outlet samples were collected using the SASS train on one test day. From these samples portions of aqueous condensate and hydrogen peroxide impinger solution were selected for elemental analysis.

Quality assurance samples for precision determinations included analysis of blind duplicate samples of refuse, bottom ash, primary collector ash, secondary collector ash, primary collector inlet particulate, and secondary outlet particulate. Standard reference materials (SRM), when available, were analyzed as unknown samples to determine analytical accuracy. SRMs which were analyzed included NBS pine needles (SRM 1575) and NBS fly ash (SRM 1633). A mixed metal standard in a hydrocarbon matrix was prepared using Conostan® organometallic standards.* Samples of aqueous condensate and hydrogen peroxide were fortified with selected metals to determine the analytical accuracy for these sample types because suitable reference materials were not available. Blanks of Gelman A/E fiberglass filter and hydrogen peroxide solution were also analyzed. Mercury analyses, which are not accurately analyzed by SSMS techniques, were performed using vapor atomic absorption methods.

---

* Conostan Division, Continental Oil Company, Ponca City, Oklahoma.

All elemental composition analyses were subcontracted to Commercial Testing and Engineering Company (CTE), Instrumental Analysis Division, Golden, Colorado.

Sample Preparation

The solid samples were prepared by mixing a 0.1-g sample with 0.1 g of ultrapure graphite in an agate mortar, adding the internal element standard along with a few drops of redistilled alcohol, and evaporating the alcohol and water from the mix with an infrared lamp. At this point the temperature reached can be as high as 180°C and may, depending upon compound form, contribute to loss of more volatile elements from the resulting SSMS sample pins.

Solid samples on fiberglass filters were prepared by first sectioning the sample plus filter and placing a section in a Pyrex centrifuge tube. The section was then covered with redistilled ethanol and the tube placed in an ultrasonic bath to separate as much sample as possible from the filter. The ethanol was then evaporated off and the tube and contents dried for 2 hr at 100°C. The tube and contents were then weighed accurately. The filter was then removed and the sample reslurried with ethanol and centrifuged to settle the sample while leaving any filter fibers suspended. The ethanol plus any filter fibers were removed by suction and the tube plus sample was again dried for 2 hr at 100°C. After cooling in a dessicator the tube and contents were weighed accurately to determine the weight of the filter. The sample was reslurried with ethanol and washed into an agate or quartz crucible and at this point was treated as a normal solid sample. The tube was then dried a third time for 2 hr at 100°C and weighed accurately to determine the tare weight.

Due to the small weight obtained, all glass filter samples were mixed in a 1:1 ratio with graphite and the internal element standard was ratioed to the individual sample weight.

The four wood samples were initially ashed to a constant weight using a LFE-302 low temperature RF plasma asher. The resulting ash was dissolved in a 1:1 ratio of ultrapure nitric acid and water. The entire solution was taken for analysis and the sample preparation carried out as for liquid samples.

The liquid samples were prepared by mixing a 20-ml aliquot of sample with 0.2 g of graphite in an agate mortar, adding the internal element standard along with a few drops of redistilled alcohol and evaporating the alcohol and water from the mix with an infrared lamp.

The resulting mix was compacted into polyethylene slugs, and the slug inserted into a metal die. Hydraulic pressure was applied to the die and slug, forming a graphite electrode, which was then mounted in the spark source for analysis.

The fuel oil samples were weighed accurately into quartz crucibles and mixed with the appropriate amount of graphite and the internal element standard. The mix was then placed in a cold muffle furnace and slowly brought to 350°C. The samples were maintained at this carbonizing temperature for 1 hr in order to eliminate hydrocarbon interference. The samples were then treated as solid samples.

All sample preparation was performed by CTE.

Samples for mercury analysis were specially prepared by CTE. The solid samples were combusted in a quartz combustion tube in the presence of a mercury-free oxygen flow. The oxygen carried the mercury vapor over two gold traps arranged in series. The gold traps were heated successively and the mercury vapor passed through a quartz cell set in the path of a mercury hollow cathode lamp.

The fuel oils were treated in the same manner as the solid samples.

The liquid samples were analyzed for mercury by placing an aliquot of the sample in a reaction vessel and adding a known volume of sodium borohydride to reduce the mercury. The mercury vapor was then carried by mercury-free oxygen to the gold traps and ultimately to the quartz cell.

The samples on filter media were analyzed for mercury by heating a section of known weight in the combustion tube and treating them as solid samples. By knowing the weight of the unused portion, the weight in micrograms was then calculated.

Sample Analysis

All SSMS analyses were performed on an AEI MS-7 mass spectrometer equipped with a photographic plate detector.

The prepared sample pins were loaded into the source of the mass spectrometer. A source vacuum pressure of at least 1 x 10^{-7} mm Hg is maintained during sparking. A series of decreasing exposures, i.e., 100, 60, 30, 10, 6, 3, 1, 0.6, 0.3, 0.1, 0.06, 0.03, 0.01, 0.006, and 0.001 nC, totaling 210 nanocoulombs is deposited on a photographic plate. This produces a permanent photoplate spectrum for interpretation.

After exposure, the photographic plate was removed from the instrument and developed using controlled developing times.

Photoplate interpretation is carried out using the "just disappearing line" method. This allows simultaneous detection of all ion spectra and spectra can be recorded at the highest available resolving power of the instrument. Reproducibility of the plate response can be as good as ± 3 to ± 5%.

The use of the photoplate allows the recording of spectra without prior knowledge of the sample, i.e., in some cases unexpected interferences in the spectra would lead to erroneous results using electrical detection methods.

Mercury was analyzed by double-gold amalgamation-flameless AA.

Quality Assurance

Precision of SSMS photoplate results, normally interpreted to be spectra read from a photoplate several times by the same analyst, can be as good as ± 20%. However, a precision value that is normally of interest is the total precision of the method on trace analysis from sample to sample. The sample-to-sample value observed in the Instrumental Analysis Division of CTE experience in a coal matrix is not better than ± 100% and is probably in the range of ± 100 to 300% at a parts per million concentration utilizing the visual "just disappearing" line technique.

Accuracy of the SSMS is, of course, related direcly to trace element standards in a given matrix and the ability to repeat analysis with precision in relation to a known standard.

It is generally agreed that the spark source value can be within a factor of three to five times the absolute elemental concentration at the parts per million level. Major component (MC) in a solid is an elemental concentration greater than 1,000 μg/g unless otherwise stated. Major component in a liquid is normally an elemental concentration greater than 10 μg/ml unless otherwise stated. When an element is reported as "heterogeneous," it means that while sparking, an enrichment or elemental inclusion was passed through and what is normally a linear function of exposures on the photographic plate is now very nonlinear. The concentration reported on a heterogeneous element is therefore probably a maximum value.

A variety of samples were analyzed to monitor analytical accuracy and precision. NBS reference fly ash (SRM 1633) and pine needles (SRM 1575) were employed as primary monitors of analytical accuracy. Possible sample matrix interferences in aqueous condensate and hydrogen peroxide solution were monitored through analysis of samples fortified with known quantities of metals of interest. Analytical accuracy of fuel oil analyses were monitored using a mixture of Conostan® organometallic standards. To monitor analytical precision, blind duplicate samples of fuel oil, wood, bottom ash, primary and secondary collector ash, and inlet and outlet Method 5 filter catch particulates for one run were submitted for analysis. The results of blind duplicate analyses are reported in the respective analysis sections. All quality assurance samples were submitted without origin identity.

Results for reference materials are summarized in Tables A-2 and A-3 for NBS fly ash and pine needles. Metal concentrations observed in NBS fly ash were compared to certified and uncertified values reported by NBS and additional values reported by Ondov et al., in Anal. Chem., 47:1102 (1975). Generally good agreement (50 to 150%) between observed and reported values was found. Of the exceptions, Ta (< 11%), Yt (43%), Cs (47%), I (31%), Br (25%), and Cr (206%), only chromium content is certified by NBS, which suggests that the remaining elements may be inhomogeneously dispersed in the reference materials, and thereby may produce variable results. Elements having the lowest recoveries (I and Br) may be lost as volatile species in the spectrometer vacuum system. Losses of Ta, Yt, and Cs are unexplained; however, the observed losses do not appear serious. The analysis of SRM fly ash was considered to reflect accuracy for all ash and particulate samples.

Selected elements in NBS pine needles (SRM 1975) were analyzed by SSMS as one measure of quality assurance for the wood elemental analyses. The results are summarized in Table A-3. In many cases, the certified values were found to exceed the SSMS analytical range, as found for Fe, Mn, Ca, K, P, and Al. Therefore, these results were not amenable to recovery calculations. An additional group of elemental concentrations are reported by NBS but not certified. These elements are Tl, Ce, La, Sb, Cd, Br, Ni, and Co. The recoveries of noncertified materials generally fell within the expected accuracy range of SSMS (± 100 to ± 300%) with the single exception of bromine. Of the certified elements, results were generally acceptable within the limits of SSMS.

The organometallic oil standard was prepared from Conostan organometallic materials. Agreement with actual values was generally acceptable (30 to 300%) as summarized in Table A-4. Several outliers which were noted include: B (< 3%); Cd (< 2%); Ca (1,000%); Fe (350%); Pb (≤ 7%); Mg (420%); and V (350%). Interactions between Ca, Mg, and V during AA analyses performed on similar materials by Conostan® were noted; however, the specific source of enhancement, interference, or contamination has not been identified. The low recovery of boron may be due to hydrolysis and subsequent losses during handling. Losses of cadmium and lead may be due to loss of volatile organocadmium or lead materials during sample preparation. The causes of high iron and magnesium recoveries are unknown.

As summarized in Table A-5, the recovery of selected metal fortifications of aqueous condensate are generally good (50 to 150%) with the exception of Ni and Be. Spectral interferences precluded accurate analysis of nickel. The loss of beryllium is currently unexplained, but may be due to loss of volatile compounds.

TABLE A-2. ELEMENTAL ANALYSIS OF NBS SRM 1633 COAL FLY ASH BY SSMS[a]

Element	Observed concentration[d] (µg/g)	Actual concentration[b] (µg/g)	Recovery (%)
Uranium	10	11.6 ± 0.2[c]	89
Thorium	25	-	-
Bismuth	0.6	-	-
Lead	54	70 ± 4[c]	77
Thallium	2	-	-
Mercury	NR	-	-
Gold	-	-	-
Platinum	-	-	-
Iridium	-	-	-
Osmium	-	-	-
Rhenium	-	-	-
Tungsten	3	4.6 ± 1.6	65
Tantalum	-	1.8 ± 0.3	< 11
Hafnium	5	7.9 ± 0.4	63
Lutetium	0.7	1.0 ± 0.1	70
Ytterbium	3	7 ± 3	43
Thulium	0.4	-	-
Erbium	3	-	-
Holmium	4	-	-
Dysprosium	6	-	-
Terbium	1	1.9 ± 0.3	53
Gadolinium	3	-	-
Europium	2	2.5 ± 0.4	80
Samarium	15	12.4 ± 0.9	121
Neodymium	26	-	-
Praseodymium	12	-	-
Cerium	76	146 ± 15	52
Lanthanum	76	82 ± 2	93
Barium	MC	2,700 ± 200	-
Cesium	4	8.6 ± 1.1	47
Iodine	0.9	2.9 ± 1.2	31
Tellurium	≤ 0.4	-	-
Antimony	5	6.9 ± 0.6	72
Tin	2	-	-
Indium	STD	-	-
Cadmium	1	1.45 ± 0.06[c]	69
Silver	≤ 0.4	-	-
Palladium	-	-	-
Rhodium	-	-	-
Ruthenium	-	-	-
Molybdenum	26	-	-
Niobium	38	-	-

(continued)

TABLE A-2. (continued)

Element	Observed concentration[a] (µg/g)	Actual concentration[b] (µg/g)	Recovery (%)
Zirconium	190	301 ± 20	63
Yttrium	64	62 ± 10	103
Strontium	MC	1,700 ± 300	-
Rubidium	63	125 ± 10	50
Bromine	3	12 ± 4	25
Selenium	14	9.4 ± 0.5[c]	149
Arsenic	49	61 ± 6[c]	80
Germanium	15	-	-
Gallium	65	-	-
Zinc	260	210 ± 20[c]	124
Copper	99	128 ± 5[c]	77
Nickel	97	98 ± 3[c]	99
Cobalt	22	41.5 ± 1.2	53
Iron	MC	6.2 ± 0.3%	-
Manganese	500	493 ± 7[c]	101
Chromium	270	131 ± 2[c]	206
Vanadium	220	214 ± 8[c]	103
Titanium	MC	7,400 ± 300	-
Scandium	17	27 ± 1	63
Calcium	MC	4.7 ± 0.6%	-
Potassium	MC	1.61 ± 0.15%	-
Chlorine	41	42 ± 10	98
Sulfur	MC	-	-
Phosphorus	MC	-	-
Silicon	MC	21 ± 2%	-
Aluminum	MC	12.7 ± 0.5%	-
Magnesium	MC	1.8 ± 0.4%	-
Sodium	MC	3,200 ± 400	-
Fluorine	∼ 460	-	-
Oxygen	NR	-	-
Nitrogen	NR	-	-
Carbon	NR	-	-
Boron	740	-	-
Beryllium	INT	-	-
Lithium	≥ 820	-	-
Hydrogen	NR	-	-

Note: NR = not reported; STD = internal standard; MC = major component > 1,000 µg/g; and INT = interference.

[a] All values in micrograms per gram except when noted.

[b] Values reported by J. M. Ondov et al., Anal. Chem., 47(7):1102 (1975).

[c] Values certified by NBS.

TABLE A-3. SSMS ELEMENTAL ANALYSIS OF NBS PINE NEEDLES SRM 1575

Element	Observed concentration (µg/g)	NBS certified concentration (µg/g)	Recovery (%)
Uranium	< 0.01	0.020 ± 0.004	< 50
Thorium	< 0.01	0.037 ± 0.003	< 27
Lead	3	10.8 ± 0.5	28
Thallium	< 0.01	0.05[a]	< 20[b]
Mercury	0.12	0.15 ± 0.05	80
Cerium	0.2	0.4[a]	50[b]
Lanthanum	0.1	0.2[a]	50[b]
Antimony	0.1	0.2[a]	50[b]
Cadmium	< 0.1	< 0.5[a]	-
Strontium	2	4.8 ± 0.2	42
Rubidium	5	11.7 ± 0.1	43
Bromine	0.1	9[a]	1[b]
Arsenic	7[d]	0.21 ± 0.04	330
Copper	4	3.0 ± 0.3	133
Nickel	1	3.5[a]	29[b]
Cobalt	0.09	0.1[a]	90[b]
Iron	> 100	200 ± 10	-
Manganese	> 100	675 ± 15	-
Chromium	2	2.6 ± 0.2	77
Calcium	MC	0.41% ± 0.02%	-
Potassium	MC	0.37% ± 0.02%	-
Phosphorus	MC	0.12% ± 0.02%	-
Aluminum	> 14	545 ± 30	-

---

[a] Noncertified values reported for informational purposes only.

[b] Recovery data based on noncertified values.

[c] Analysis by atomic absorption methods.

[d] The observed value reflects its maximum amount of material present due to a heterogeneous signal.

TABLE A-4. SSMS QUALITY ASSURANCE ANALYSIS OF TRACE METALS IN OIL

Element	Observed concentration (μg/g)	Reported[a] concentration (μg/g)	Recovery (%)
Aluminum	0.5	1.44	35
Antimony	0.5	1.50	33
Arsenic	0.5	1.61	31
Barium	2	1.44	140
Boron	≤ 0.05	1.44	≤ 3
Cadmium	< 0.03	1.44	< 2
Calcium	15	1.44	1,000
Chromium	3	1.44	210
Copper	0.7	1.44	49
Iron	5	1.44	350
Lead	≤ 0.1	1.44	≤ 7
Magnesium	6	1.44	420
Manganese	1	1.44	69
Mercury	2.42[b]	1.72	140
Molybdenum	1	1.44	69
Nickel	1	1.44	69
Phosphorus	1	1.44	69
Selenium	0.3	1.51	20
Silver	0.9	1.44	63
Silicon	MC[c]	1.44	> 100
Sodium	0.2	1.44	14
Tin	0.6	1.44	42
Titanium	3	1.44	210
Vanadium	5	1.44	350
Zinc	0.2	1.44	14

[a] Based on dilutions of stock concentrations of Conostan® organometallic standards, supplied by Conostan Division, Continental Oil Company, Ponca City, Oklahoma.

[b] Flameless atomic absorption analysis.

[c] MC = major component.

TABLE A-5. SSMS ANALYSIS OF SELECTED ELEMENTAL FORTIFICATIONS IN AQUEOUS CONDENSATE

Element	Total observed content (µg)	Background condensate content (µg)	Observed fortification (µg)	Actual fortification (µg)	Recovery (%)
Lead	200	< 2	200	200	100
Mercury	115	0.5	114.5	200	58
Antimony	150	< 0.5	150	200	75
Cadmium	125	< 0.5	125	200	63
Selenium	250	≤ 0.75	250	200	125
Arsenic	225	5	220	200	110
Zinc	225	75	150	200	75
Copper	200	20	180	200	90
Nickel	INT	500	-	400	-
Manganese	> 250	75	> 175	200	≥ 90
Chromium	> 250	1,200	> 250	1,000	UNK
Vanadium	> 250	2.5	> 248	200	≥ 125
Titanium	> 250	15	> 235	200	≥ 118
Beryllium	< 0.05	< 0.5	-	200	0

Note: INT = interference.
UNK = unknown.

Conclusive data for Mn, Cr, V, and Ti was not available because the quantitative analytical range of the SSMS is exceeded for these elements; however, minimum recoveries were calculated for Mn, V, and Ti.

The recovery of selected metal fortifications in 30% hydrogen peroxide solution also was generally good (50 to 150%) as tabulated in Table A-6. Low recoveries of Sb (40%), Cd (20%), and Pb (40%) were observed which has been attributed to the relatively high volatility of these elements and their compounds. Losses most likely occur during sample preparation or during analysis in the spectrometer vacuum system. Two other potentially volatile elements, As and Se, were recovered at levels of 100 and 140%, respectively, indicating no losses during sample preparation or analysis. Unidentified interferences precluded the analysis of beryllium in the fortified peroxide solution.

TABLE A-6. ELEMENTAL ANALYSIS OF FORTIFIED 30% HYDROGEN PEROXIDE BY SSMS

Element	Observed concentration (μg/ml)	Reported concentration (μg/ml)	Recovery (%)
Antimony	2	5	40
Arsenic	5	5	100
Beryllium	INT	5	-
Cadmium	1	5	20
Chromium	3	5	60
Copper	6	10	60
Iron	~ 12	10	120
Lead	2	5	40
Manganese	3	5	60
Nickel	6	10	60
Selenium	7	5	140
Titanium	7	5	140
Vanadium	3	5	60
Zinc	9	10	90

Note: INT = interference.

Problems

General good agreement between observed and reported values for reference materials and fortified samples were observed. The most prevalent problem observed was the loss of the more volatile elements such as cadmium or lead which may be expected. Other problems associated with a specific element or sample matrix are discussed in the quality assurance section.

Reference

Conostan Division, Continental Oil Company, Ponca City, Oklahoma.

POLYNUCLEAR AROMATIC HYDROCARBON ANALYSIS

Samples

Samples of bottom ash, primary collector ash, secondary collector ash, and aliquots of Florisil train extracts were analyzed for selected hydrocarbon and heterocyclic PAH materials. A duplicate of each ash sample type, a fortified sample of each sample type, and reagent blanks were analyzed for quality assurance.

Sample Preparation

Ash samples were prepared specifically for PAH analysis as described in the following section. Florisil train components were extracted for PCB analysis and were subsequently aliquoted for PAH analysis. The preparation of Florisil train samples is only briefly described in this section. Additional detail on preparation of Florisil train samples is presented in the PCB analysis section. All samples were fortified to a concentration of 40 to 80 ng/μl of D-10 anthracene as an internal standard prior to GC/MS analysis.

Approximately 20 g of each ash sample were mixed with preextracted anhydrous sodium sulfate to form a free-flowing mixture prior to extraction with 150 ml of methylene chloride in Soxhlet extractors for 8 hr. The Soxhlet extractors were wrapped with aluminum foil to protect the samples from light. The sample extracts were subsequently concentrated to a volume of 5 ml with aluminum foil-wrapped Kuderna-Danish evaporators. All samples were stored in the dark at 4°C prior to analysis.

Samples from the Florisil train components were aliquoted prior to the sulfuric acid treatment, which is prescribed for PCB analysis, and analyzed directly.

Sample Analysis

Preliminary sample analysis was attempted using a capillary GC equipped with a flame ionization detector (FID); however, the complex chromatograms observed precluded successful interpretation and necessitated use of GC/MS analysis. Samples were analyzed by GC/MS using a 10 m, SE 30 SCOT capillary column. Identification and quantitative determination of specific PAH compounds was made based on retention times and extracted ion plots characteristic of the compounds of interest.

The chromatographic conditions used for the capillary column analysis of samples for PAH are given in Table A-7. A reconstructed ion chromatogram (RIC) of the 14-component standard is presented in Figure A-1. As illustrated, two clustered peaks are produced by more than one compound. With selective ion monitoring, it was found that chromatographic resolution was achieved for phenanthrene and anthracene at scans 561 and 574, respectively, as shown in Figure A-2. Although anthracene and D-10 anthracene were not clearly resolved chromatographically, mass resolution was accomplished for ions at m/e 178 and 188, respectively, as also illustrated in Figure A-2. Similarly, the cluster at scan 1173 produced by 1,2-benzanthracene and chrysene was resolved as illustrated in Figure A-3.

TABLE A-7. GC/MS OPERATING CONDITIONS FOR PAH ANALYSIS

Column: 10 m SE 30 SCOT capillary
Column temperature: Initial hold 100°C for 4 min, program rate 8°C/min to 260°C
Instrument: Finnigan 4000
Injection mode: Splitless
Column pressure: 2 psi
Scan rate: 1.2 sec/mass decade
Scan range: 400-400 amv
Ionization potential: 70 ev
Emission current: 0.2 ma
Multiplier voltage:

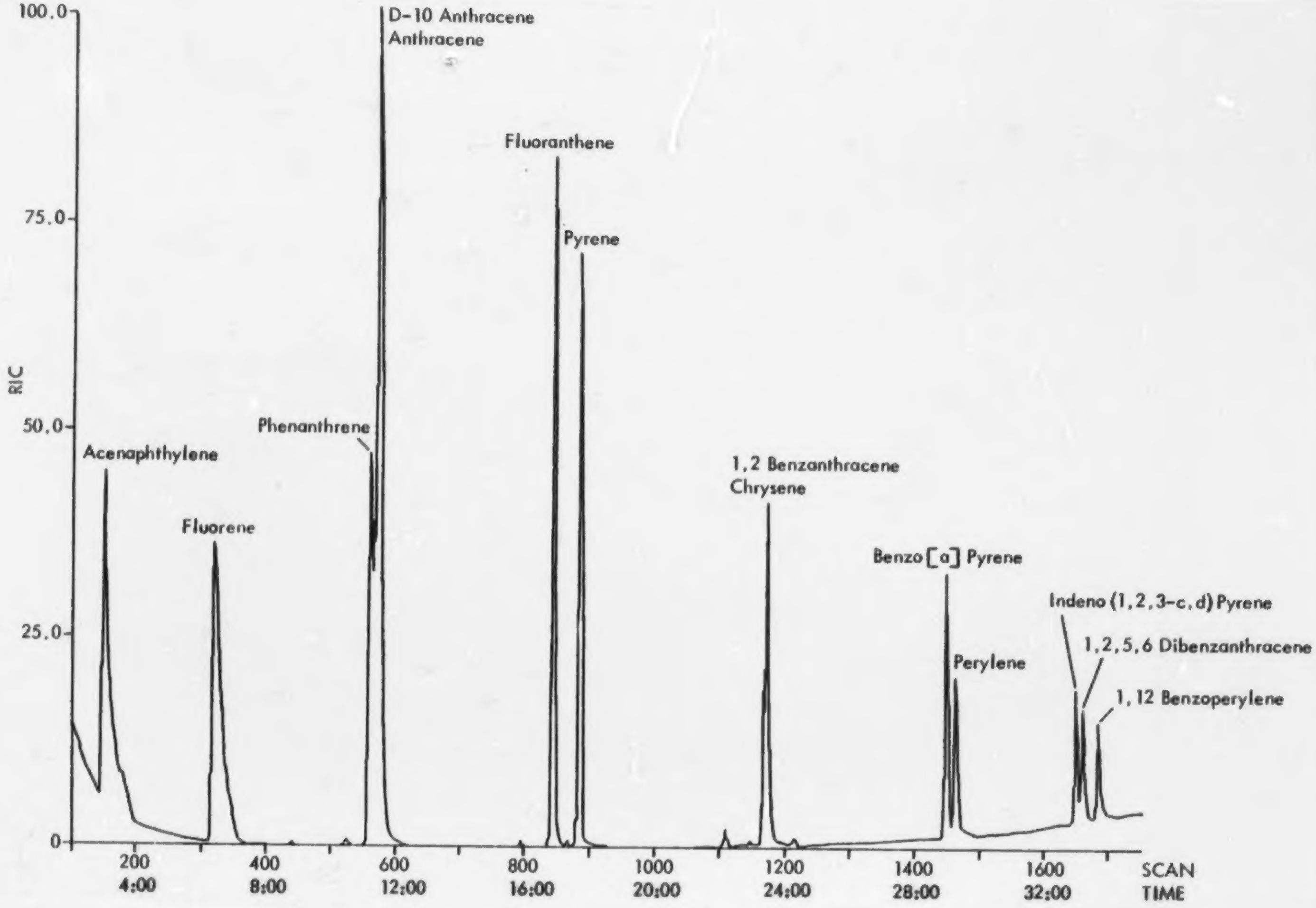


Figure A-1. Reconstructed ion chromatogram for PAH standard.

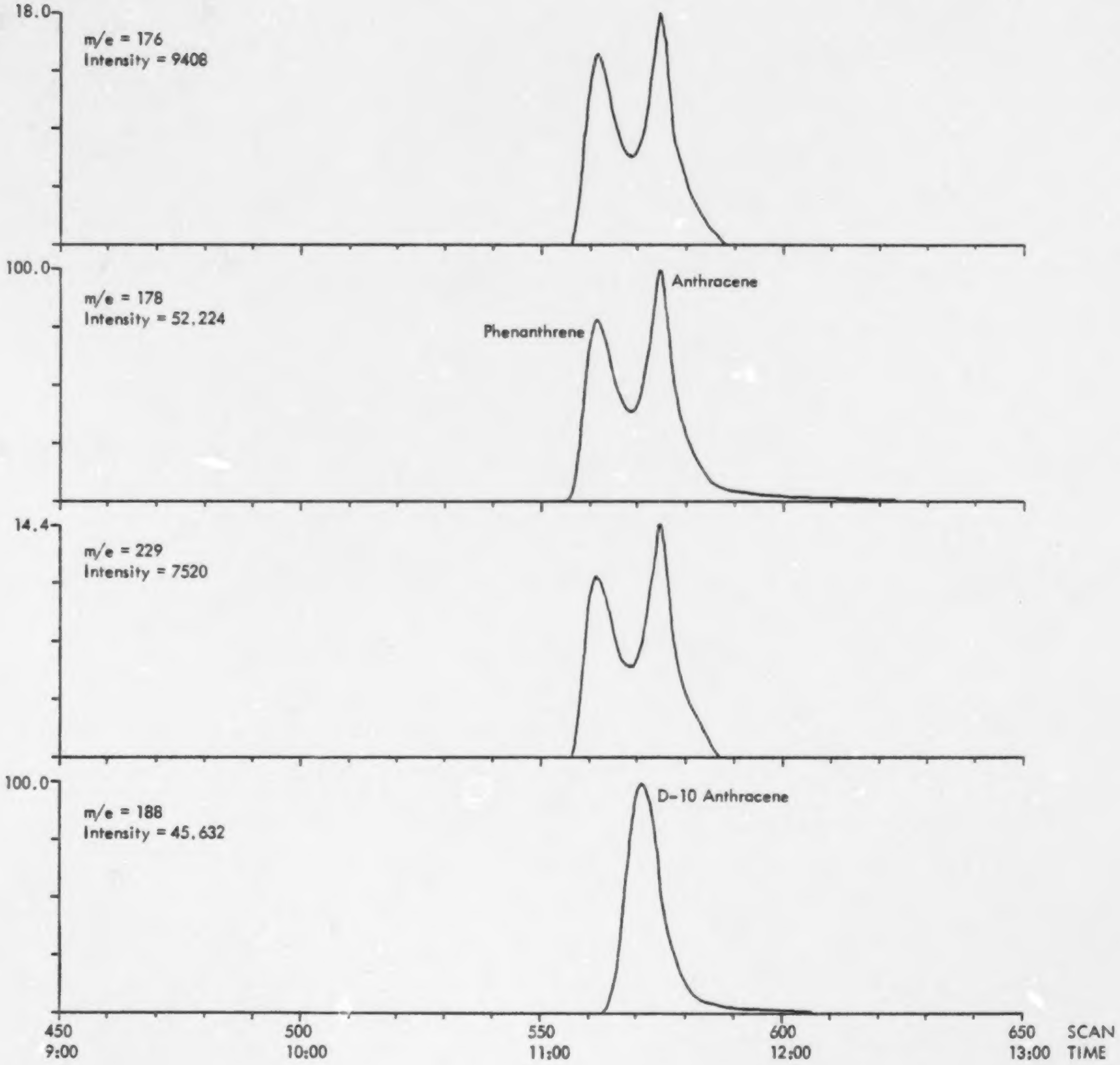


Figure A-2. Chromatographic resolution of phenanthrene, anthracene, and D-10 anthracene.

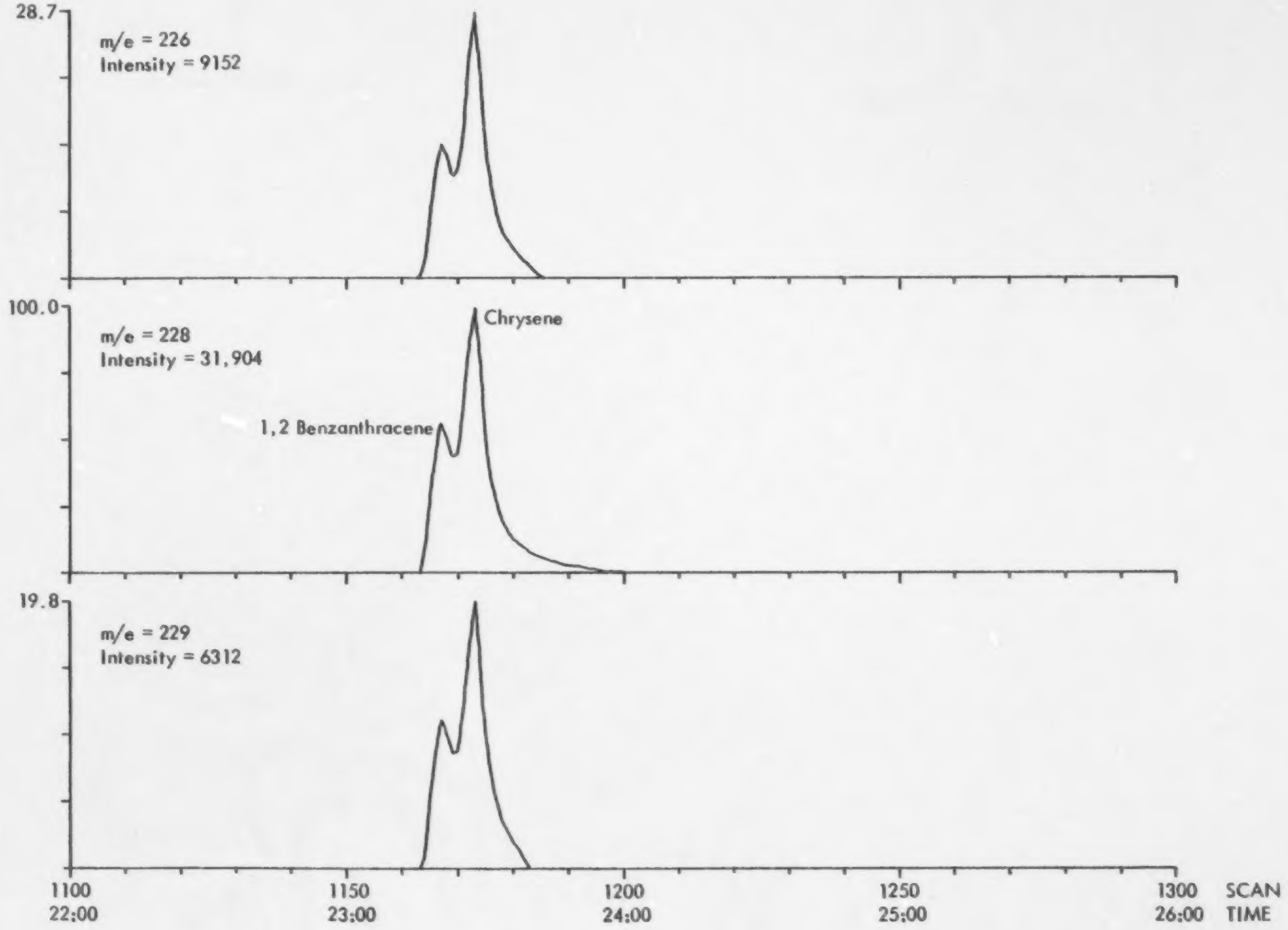


Figure A-3. Chromatographic resolution of 1,2-benzanthracene and chrysene.

A relatively simple heterocyclic PAH standard was prepared from carbazole, dibenzothiophene, and three benzoquinoline isomers, 3,4-, 5,6-, and 7,8-benzoquinoline. The RIC from a 20 ng/ml standard solution analyzed using the same chromatographic conditions as used for the hydrocarbon PAH materials is illustrated in Figure A-4. Chromatographic separation was achieved for each compound type; however, the benzoquinoline isomers were neither chromatographically nor mass resolved. Sample data was screened using selective ion plots for the three most intense ions of each heterocycle standard; however, these heterocyclic compounds were not observed in any sample.

The RIC for a secondary collector ash extract is shown in Figure A-5 and is generally indicative of the chromatographic complexity of secondary collector ash and bottom ash extracts. Relatively simple RICs were observed for primary collector ash and Florisil train extracts. In all cases, extracted ion plots were made using the three ions of highest intensity characteristic for each of the PAH compounds. Identifications were based on the presence of the three ions maximized at the correct retention time and with the correct ratio of intensities. Figure A-5 illustrates the positive identification of fluoranthene and pyrene in a secondary collector ash extract. Confirmation was obtained from the full mass spectral data of the highest intensity chromatographic scan corresponding to a suspected PAH. Mass spectral data were visually interpreted and submitted to computerized searching of a 25,000 compound library to identify compounds producing similar mass spectra. Quantitative analysis was achieved by converting digital peak intensity values to concentration values using instrumental response factors based on analyses of standards.

Quality Assurance

One sample of each ash type was prepared in duplicate for determination of analytical precision. Fortified samples of each ash type, and fortified blanks of methylene chloride, Florisil, and impinger solution were prepared and carried through the complete extraction and concentration steps to monitor preparative efficiency. Blanks of methylene chloride, Florisil, and impinger solution were analyzed to identify background reagent PAH levels. All samples were protected from heat and light. An internal standard of D-10 anthracene was added to compensate for retention time variations and response variability. Prior to analysis, the MS was calibrated with perfluorokerosene. Standards at three levels were analyzed intermittently throughout the sample analyses.

Recoveries for fortified samples, as shown in Tables A-8 and A-9, were found to vary from one PAH to another and also among different sample types. Difficulty in the recovery of many PAH materials from both the primary and secondary collector ash appears to be a result of the inability of methylene chloride to extract PAH from collector ashes in a Soxhlet extractor. This conclusion is based primarily on low extraction recoveries of long retention time PAH compounds fortified at both low and high (10 times low) fortification levels.

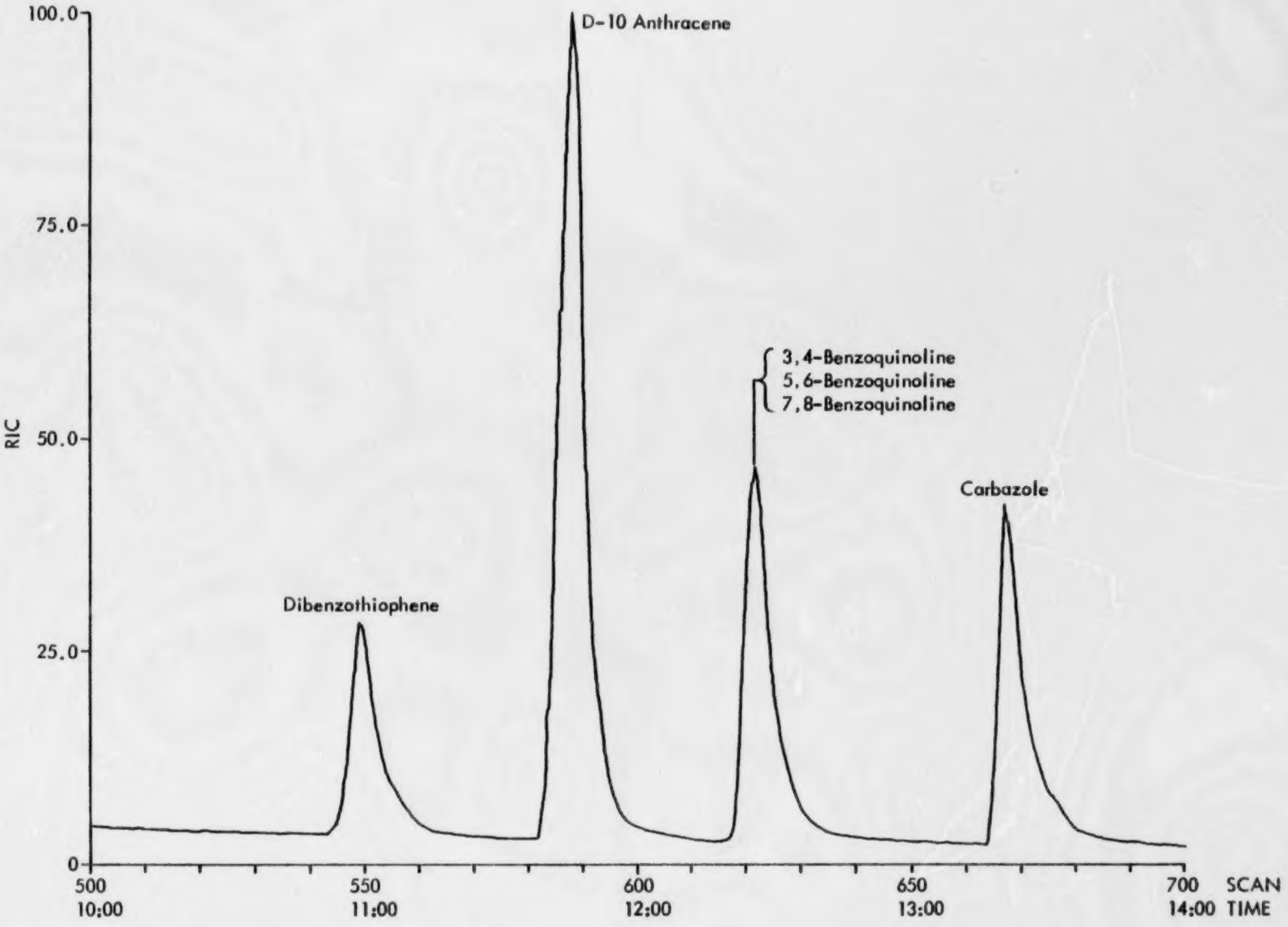


Figure A-4. Chromatogram of heterocyclic PAH standard.

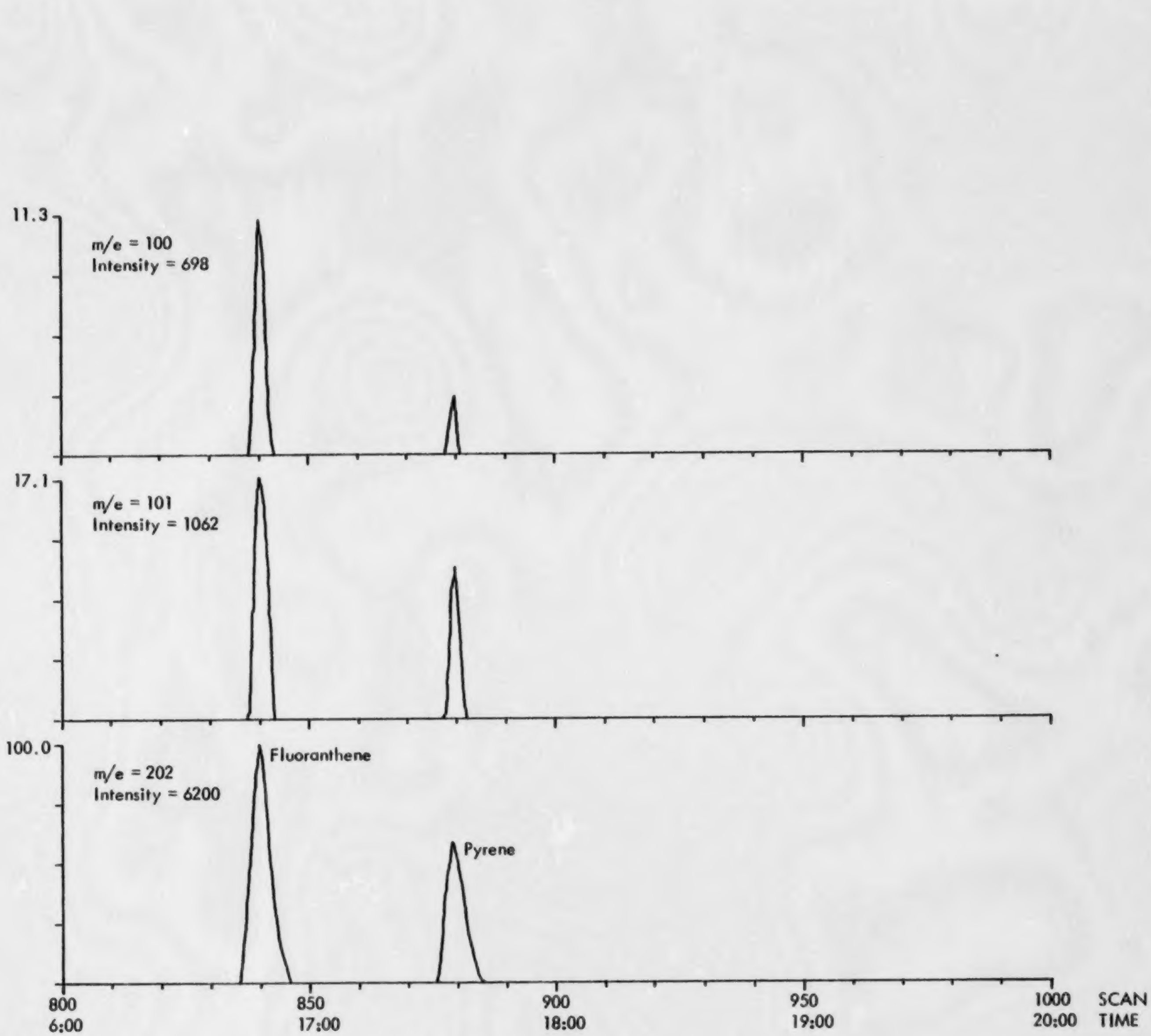


Figure A-5. Identification of fluoranthene and pyrene in secondary collector ash.

TABLE A-8. QUALITY ASSURANCE DATA FOR LOW LEVEL PAH FORTIFICATION OF SELECTED SAMPLES

Compound	Total fortification quantity (μg)	Fortified solvent		Bottom ash		Primary collector ash		Secondary collector ash	
		Observed quantity (μg)	Recovery (%)	Observed quantity[a/] (μg)	Recovery (%)	Observed quantity[a/] (μg)	Recovery (%)	Observed quantity[a/] (μg)	Recovery (%)
Acenaphthylene	187.8	116.8	62	94.8	51	65.8	35	84.9	45
Fluorene	185.3	134.1	72	103.9	56	101	55	142	77
Phenanthrene	162.1	129.0	80	111.2	69	24.5	15	104[b/]	64[b/]
Anthracene	131.1	106.4	81	57.4	44	9.67	7	99.0	75
Fluoranthene	146.7	142.6	97	87.4	60	7.95	5	18.2[b/]	12[b/]
Pyrene	123.1	118.6	96	75.3	61	6.11	5	42.6[b/]	35[b/]
Chrysene	95.5	106.0	111	77.0	81	0	0	9.6	10
1,2-Benzanthracene	133.5	133.7	100	39.7	30	1.45	1	10.3[b/]	8[b/]
Benzo[a]pyrene	135.8	146.0	108	53.0	39	0	0	0	0
Perylene	73.7	86.5	117	35.3	48	0	0	0	0
Indeno[1,2,3-c,d]pyrene	129.3	183.6	142	61.0	47	0	0	0	0
1,2,5,6-Dibenzanthracene	112.0	164.6	147	41.6	37	0	0	0	0
1,12-Benzoperylene	79.1	109.2	138	44.0	56	0	0	0	0

a/ Values corrected to D-10 anthracene internal standard.

b/ Values corrected for sample contribution.

TABLE A-9. GC/MS QUALITY ASSURANCE DATA FOR SELECTED LONG RETENTION TIME PAH COMPOUNDS

Compound	Total fortification quantity (µg)	Primary collector ash		Secondary collector ash	
		Observed quantity (µg)	Recovery (%)	Observed quantity (µg)	Recovery (%)
Chrysene	1,162	92.2	8	71.8	6
1,2-Benzanthracene	1,202	205	17	181	15
Benzo[a]pyrene	1,328	58.0	4	46.4	3
Perylene	826	44.8	5	34.9	4
Indeno[1,2,3-c,d]pyrene	1,320	4.6	0.4	32.5	2
1,2,5,6-Dibenzanthracene	763	0	0	0	0
1,12-Benzoperylene	1,256	18.1	1	21.8	2

Analytical precision for selected PAH materials in ash extracts is summarized in Table A-10. A relative deviation of 17% for two analyses of phenanthrene was the only precision measurement possible for bottom ash. Relative deviations ranging from 6 to 48% were observed for PAH compounds detected in secondary collector ash. The most likely source of large analytical variability is in the relatively low concentrations actually analyzed and large back-calculation multipliers which tend to enhance small variations. Precision calculations were not made for analyses of primary collector ash and Florisil train component extracts, since the quantity of PAH materials were at or below the analytical detection limits.

Problems

The most serious problem encountered was the inability to quantitatively recover selected PAH compounds from primary and secondary collector ashes. The problem observed appears to result from the inability to extract the PAH compounds efficiently from the collector ash matrix. This conclusion is based on the good recoveries of fortifications from the bottom ash materials. Additionally, the recoveries of PAH compounds from primary collector ash have been generally lower than the recoveries of the same materials from secondary collector ash. Similar observations during the PCB analysis reinforce the conclusion that primary and secondary collector ashes are significantly different in their ability to absorb or adsorb organic material and most likely are different in their chemical composition. Since many PAH sample concentrations were found at levels at or below the analytical detection limits, precision calculations could not be made in most cases.

TABLE A-10. ANALYTICAL PRECISION OF SELECTED PAH COMPOUNDS IN ASH EXTRACTS

Compound	Run 1 (μg/g)	Run 1 duplicate (μg/g)	Average (μg/g)	Relative deviation (± %)
Bottom ash				
Phenanthrene	0.56	0.40	0.48	17
Secondary collector ash				
Acenaphthylene	2.2	2.5	2.35	6
Phenanthrene	6.0	3.5	4.75	26
Fluoranthene	1.6	0.62	1.11	44
Pyrene	0.90	0.32	0.61	48

POLYCHLORINATED BIPHENYL ANALYSIS

Samples

Bottom ash, primary collector ash, and secondary collector ash samples were specifically prepared and analyzed for PCB material. Impinger contents and Florisil from Florisil sampling trains for vaporous PCB materials were also prepared and analyzed. Samples of wood and fuel oil were not analyzed for PCB materials due to low levels observed in the effluent materials. One sample of each ash type was analyzed in duplicate.

Sample Preparation

Approximately 20 g of each ash sample was mixed with preextracted anhydrous sodium sulfate to form a free-flowing mixture prior to extraction with 150 ml of hexane in Soxhlet extractors for 8 hr. The hexane extracts were concentrated to approximately 5 ml in Kuderna-Danish evaporators, transferred, and the volumes adjusted to 1 ml. Florisil train extracts were aliquoted into two equal volume quantities for PCB and PAH analysis. All ash extracts and one aliquot of each Florisil train extract were cleaned by shaking with 5 ml of concentrated sulfuric acid.

Sample Analysis

All extracts were screened on a Varian 1400 GC using a scandium tritide electron capture detector. The glass column (1.8 m x 2 mm ID), packed with 3% SP-2401 on 100/120 mesh Supelcoport, was operated isothermally at 190°C with a nitrogen flow of 30 ml/min. The extracts were screened against approximately 1 ng/µl standards of Arochlor 1254 and 1260. Samples producing no responses corresponding to any single component in either Arochlor standard at approximately 1 ng/µl concentrations were eliminated from additional analyses. Samples which produced responses which corresponded to Arochlor components or which produced significantly higher responses than the 1 ng/µl Arochlor standard were submitted for subsequent GC/MS analysis.

GC/MS was used to confirm the presence of PCB residues in portions of selected extracts. The GC/MS system consisted of a Varian MAT 311-A MS interfaced with a Varian 3700 GC via a two-stage Watson-Bieman separator. The MS, controlled by a Varian 620/i MS data system, was sequentially focused on m/e 222, 224, 256, 258, 290, 292, 324, and 326 for di-, tri-, tetra-, and pentachlorobiphenyls. The GC column, as described for screening, was held isothermally at 180°C and was eluted with helium at a flow rate of 30 ml/min. PCB materials were identified by coincident peaks in the two plots for a particular chlorobiphenyl with the characteristic relative intensities. The sensitivity of the system was established by assaying an Arochlor 1254 standard.

Quality Assurance

Quantitative analysis of PCB was made using pattern recognition and response measurement as outlined in "Methods for Determining the PCB Emissions from Incineration and Capacitor and Transformer Filling Plants." The results for EC/GC analysis of selected fortified samples are presented in Table A-11. Good recoveries (96 to 130%) of Arochlor 1254 from heated solvent, Florisil, and bottom ash were found. Recoveries of Arochlor 1254 components from fortified primary collector ash were found to be highly variable, ranging from 9 to 91%. This observation suggests the selective sorption of specific PCB compounds and is indicative of a significantly different sample matrix than previously encountered. The results of GC/MS analysis of Florisil train impinger water, primary collector ash, and secondary collector ash fortified with Arochlor 1254 are presented in Table A-12. Good recoveries (100%) of the Arochlor fortification were observed for secondary collector ash; however, recoveries of both low and high level fortifications from the primary collector ash were found to be highly variable and similar to those observed in the low level EC/GC fortification. Since compound stability and preparative losses do not appear to be serious at low levels (~0.8 µg of Arochlor 1254), losses at high fortification levels strongly implicates selective compound sorption. Since all sample responses were at or below the instrumental detection limits, precision calculations were not possible.

TABLE A-11. RECOVERY OF AROCHLOR 1254 FORTIFICATIONS FROM SELECTED SAMPLES ANALYZED BY EC/GC[a]

Component number	Fortified reagent	Florisil (%)	Bottom ash (%)	Primary collector ash
1	103	108	98	0
2	91	112	80	91
3	97	100	67	80
4	95	117	76	29
5	94	139	118	0
6	97	152	122	58
7	98	154	124	9
8	96	155	122	30
Average recovery	96 ± 3	130 ± 23	101 ± 24	[b]

[a] Determined for a fortification of 0.8 μg of Arochlor 1250 in all cases.

[b] An average recovery of 37% was found for a recovery range of 0 to 91%.

TABLE A-12. QUALITY ASSURANCE DATA FOR GC/MS ANALYSIS OF PCB FORTIFIED SAMPLES

Component	Fortified solvent[a]	Fortified impinger water[a]	Primary collector ash		Secondary collector ash	
			5 µg/g[a]	50 µg/g[b]	5 µg/g[a]	50 µg/g[b]
Dichlorobiphenyl						
Peak 1	100	INT	39	76	INT	89
2	100	INT	119	55	INT	63
3	100	75	63	0	INT	81
4	100	100	0	0	INT	75
Trichlorobiphenyls						
1	89	95	61	72	INT	89
2	97	103	47	66	77	105
3	95	105	32	58	100	100
4	96	96	6	20	69	100
5	96	144	0	0	59	67
6	111	156	0	0	67	44
Tetrachlorobiphenyls						
1	96	180	20	76	128	152
2	94	135	0	65	153	141
3	120	184	0	18	120	150
4	101	165	7	0	110	113
5	130	174	65	91	96	96
6	96	153	42	65	92	100
7	96	193	24	41	80	96
Pentachlorobiphenyls						
1	118	221	118	82	176	165
2	103	194	56	69	131	152
3	94	141	50	56	103	113
4	123	524	16	18	150	142
5	107	302	0	0	81	79
6	113	300	0	0	56	47

Note: INT = interference.

[a] Fortification of 100 µg of Arochlor 1254.

[b] Fortification of 1,000 µg of Arochlor 1254.

The recovery of an Arochlor 1254 fortification after extraction from a blank Florisil train impinger water and rinse was found to be approximately 100% or greater as summarized in Table A-12. The elevated recoveries have been attributed to background contamination of this sample by Arochlor 1254. Florisil and reagent blanks were analyzed in all phases of analysis to identify potential contamination sources.

Problems

Extracts of bottom ash and secondary collector ash were found to produce complex chromatograms by EC/GC which necessitated GC/MS analysis for identification and verification. The variable, selective recoveries of PCB fortifications, and the relatively simple chromatograms from primary collector ash are indicative of a significantly different sample matrix which suggests the presence of a strong sorbent material.

A single sample of impinger water from the second run of the Florisil train produced patterns corresponding to Arochlor 1254. Considering the lack of detectable PCB in the remaining train components, location of the impinger in the train, and the direct correspondence of sample and standard responses, the sample responses were discounted as low level contamination, most likely originating in the concentration step.

Reference

Haile, C. L., and E. Baladi. Methods for Determining the Total Polychlorinated Biphenyl Emissions from Incineration and Capacitor - and Transformer-Filling Plants. EPA-600/4-77-048, November 1977.

LEVEL 1 ANALYSIS METHODS

Samples

Level 1 environmental assessment methods for particulate-containing gases were included in the test program. Samples of the outlet gas stream were collected using the SASS train during the second test day. Organic analyses were performed on all SASS train samples including particulates, XAD-2 resin, aqueous condensate, train rinses, and reagent blanks. Inorganic analyses were performed only on the aqueous condensate and the hydrogen peroxide impinger solutions. These analyses were performed according to the method contained in "IERL-RTP Procedures Manual, Level 1 Environmental Assessment" (EPA-600/2-76-160), and included any revisions available at the time of sample analysis. Only selected inorganic gas analyses were performed on site, and no organic GC analyses for C-1 through C-6 compounds were performed on site. Continuous on-site analyses for the following gases were performed: O_2, NO_x, SO_2, hydrocarbons, CO_2, and CO.

The organic Level 1 analysis protocol is unique to Level 1 and is not covered in other sections of this appendix. Therefore, only organic Level 1 analyses will be discussed in this section.

Sample Preparation

Sample preparation methods used were those defined in EPA-600/2-76-160a, a draft revision of Chapter 8 received November 22, 1977, and subsequent applicable revisions, which were received May 31, 1978. Samples were extracted with methylene chloride, aliquoted, and concentrated to a volume of 10 ml using Kuderna-Danish evaporators. A sample aliquot which contained an amount of TCO material between 10 and 100 mg was either evaporated to dryness or solvent-exchanged depending on its TCO level. LC fractionation on silica gel was performed on this sample aliquot and seven fractions collected for subsequent analysis. The above sequence of sample preparation steps, and decision making criteria, are schematically shown in Figure A-6. A summary of samples prepared and the analyses subsequently performed on them are presented in Table A-13.

Particulate samples were combined for extraction of organic material. The combined particulate samples were subsequently extracted with methylene chloride. The results of particulate analyses are reported as "total particulate" values due to the combination of particulates.

XAD-2 resin was prepared before use according to the procedure in the draft revision of Chapter 8 of the Level 1 protocol. The XAD-2 samples were Soxhlet-extracted using only methylene chloride, after testing, as specified in the draft revisions. Aqueous condensate was adjusted to pH 2 and 12, respectively, and extracted with methylene chloride at each pH. The extracts were then combined before analysis.

Since the particulate weight contained in the front half rinse accounted for greater than 10% of the total particulate collected after weighing, the rinse particulates were Soxhlet-extracted with methylene chloride for organic analysis.

Sample Analysis

Organic Level 1 methods include gravimetric measurement of low volatility components (GRAV), IR analysis, determination of TCO, and mass spectral (direct inlet and batch inlet) procedures (LRMS). Analytical methods for each procedure are discussed below.

GRAV determinations were performed on all unconcentrated samples and LC fractions by evaporation of an aliquot (5 ml) of methylene chloride extract or LC solvent fraction. GRAV determinations of concentrated samples were made by evaporation of 1-ml aliquots.

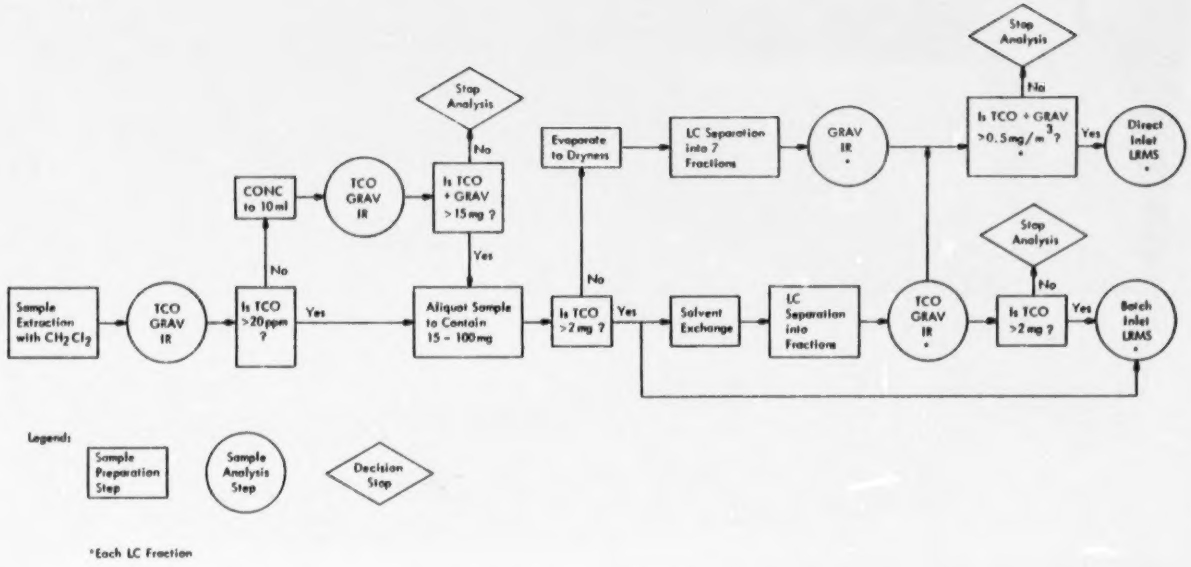

Sample Extraction with CH_2Cl_2
TCO GRAV IR
Is TCO >20 ppm ?
No
Yes
CONC to 10 ml
TCO GRAV IR
Is TCO + GRAV >15 mg ?
No
Stop Analysis
Yes
Aliquot Sample to Contain 15 – 100 mg
Is TCO >2 mg ?
No
Yes
Evaporate to Dryness
LC Separation into 7 Fractions
GRAV IR *
Is TCO + GRAV >0.5 mg/m^3 ? *
No
Stop Analysis
Yes
Direct Inlet LRMS *
Solvent Exchange
LC Separation into Fractions
TCO GRAV IR *
Is TCO >2 mg ?
No
Stop Analysis
Yes
Batch Inlet LRMS *
Legend:
Sample Preparation Step
Sample Analysis Step
Decision Step
*Each LC Fraction

Figure A-6. Organic Level 1 analysis flow diagram.

TABLE A-13. LEVEL 1 ORGANIC SAMPLE SUMMARY

Sample prepared	Preliminary analysis			Concentrate analysis				Analysis terminated	Solvent exchange	LC fractionation	Analysis of all LC fractions			Analysis terminated
	TCO	GRAV	IR	TCO	GRAV	IR	LRMS[a]				TCO	GRAV	IR	
Particulate	X	X	X	X	X	X	-	X	-	-	-	-	-	-
Front rinse	X	X	X	X	X	X	-	X	-	-	-	-	-	-
XAD-2 field sample	X	X	X	X	X	X	X	-	X	X	X	X	b/	X
Aqueous condensate	X	X	X	X	X	X	-	X	-	-	-	-	-	-
Organic module rinse	X	X	X	X	X	X	-	X	-	-	-	-	-	-
Methylene chloride blank	X	X	X	X	X	X	-	X	-	-	-	-	-	-
XAD-2 blank	X	X	X	X	X	X	X	-	X	X	X	X	-	X
Filter blank	X	X	X	X	X	X	-	X	-	-	-	-	-	-

a/ Direct inlet LRMS only.

b/ IR spectra were taken only of samples producing measurable gravimetric weight, LCG and LCF.

IR spectra were taken from the GRAV residues. The samples were prepared by dissolving the residue in a minimum amount of methyl chloride and transferring the solution to KBr plates. The methylene chloride was then evaporated and the IR spectra taken. GRAV samples resulting in no measurable weight gain were not submitted for IR analysis. A Beckman IR-12 spectrophotometer was used to obtain the IR spectra.

TCO analyses were performed using a Varian 2400 GC with flame ionization detector. A glass column (1.83 m x 2 mm ID), packed with 1.5% OV-101 on Gas Chrom Q, 100/120 mesh, was used. The temperature conditions were: 4 min initial hold at 50°C; temperature programmed from 50 to 250°C at 20°C/min; inlet temperature, 200°C; and detector temperature, 275°C. Chromatograms were recorded on an HP Model 3380A recording integrator. Sample volumes of 5 µl were used for TCO analyses.

Direct inlet LRMS of the XAD-2 field sample and XAD-2 field blank was performed. MS analyses were performed using a Varian MAT CH-4 with a Varian 620/i data system. Thermograms from 50 to 460°C at approximately 50°C/min were performed on the direct inlet samples. The MS operating conditions are listed in Table A-14.

TABLE A-14. LRMS OPERATING CONDITIONS

Ionizing voltage	70 eV
Ionizing current	40 µa
Multiplier voltage	2.3 kV
Mass range	0-500 m/e
Scan rate	5 sec/mass decode

IR spectra obtained from concentrated XAD-2 resin and XAD-2 LC Fractions 6 and 7 consisted primarily of absorbance peaks characteristic of carbonyl-containing hydrocarbon materials. The IR spectrum observed for the XAD-2 LC Fraction 6 is illustrated in Figure A-7. The major absorption peaks are generally characteristic of aliphatic or aromatic carbonyl-containing compounds. The low prevalence, or absence, of materials containing hydroxyl and/or carboxylic acid functional groups is suggested by the absence of intense broad band absorption in the region of 3000 to 3400 cm^{-1} for LC Fractions 6 and 7. These functional group assignments were typical of the IR data for samples producing interpretable IR spectra. Compound identification beyond the functional group assignments was not attempted due to the large number of peaks

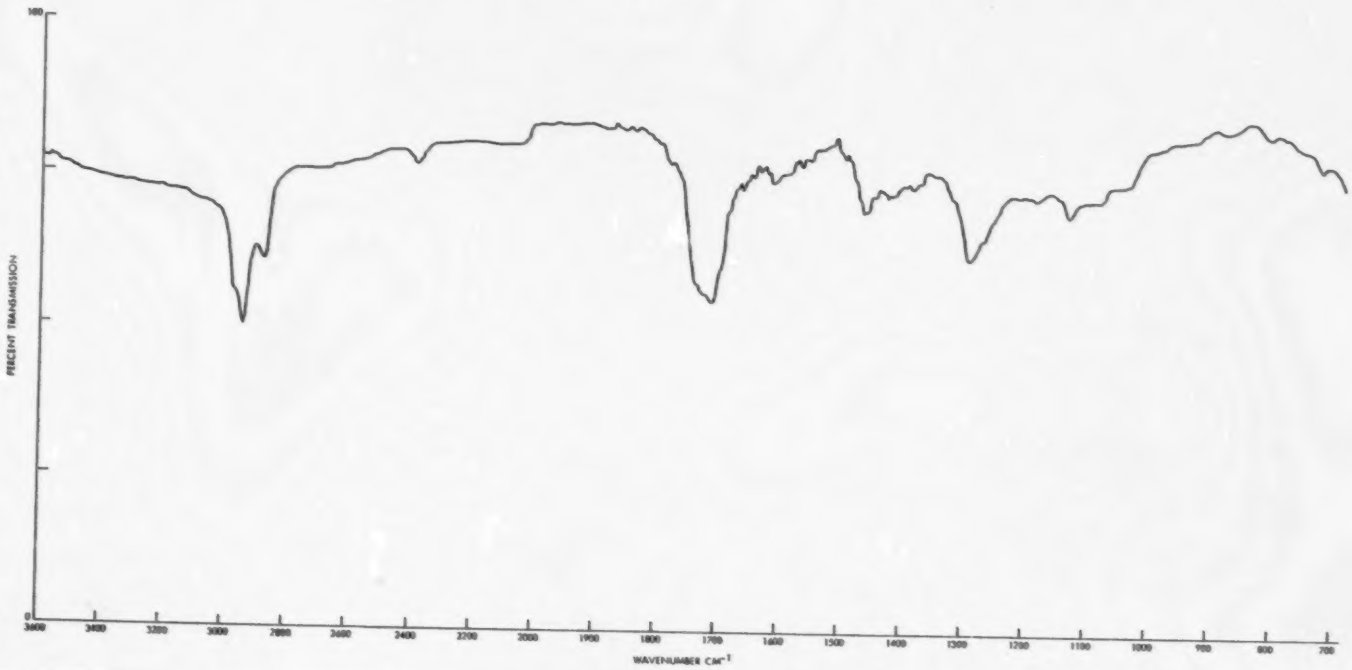


Figure A-7. IR spectrum for LC Fraction 6 of XAD-2 resin.

observed in the TCO analyses. With the exception of the XAD-2 LC Fractions 6 and 7 and concentrated XAD-2 extract, sample extracts were not found to produce IR spectra of sufficient intensity to allow interpretation.

The TCO chromatogram for concentrated XAD-2 resin extract prior to LC fractionation is shown in Figure A-8, which depicts a complex mixture containing in excess of 50 components, many beyond the specified C-17 cutoff for TCO analysis. Additional low concentration materials may be unobserved in the continuum of overlapping peaks. After LC fractionation, the bulk of the collected material was observed in the polar sixth and seventh fractions.

The direct inlet LRMS analysis of XAD-2 sample and blank extracts was performed. Thermograms and ion range plots were constructed to identify scanning regions of interest. Spectra from each selected scan range were compared. As illustrated in Figure A-9, a complex mixture of ions was observed for each range of interest. Detectable ions were observed through the mass range of each scan. Comparison of sample and blank data indicated serious background problems from the less volatile components in both extracts. Due to the mixture complexity, spectral complexity, and high background levels, detailed interpretation of this data was not attempted.

Quality Assurance

Quality control was carried out in accordance with those procedures specified in the draft revision for Level 1 organic analysis. Samples for quality assurance include those for calibration procedures and analysis of blanks. Specific procedures used are described below.

TCO analyses were performed using commercially prepared standard mixtures containing C_6-C_{10} compounds and C_{10}-C_{18} compounds for retention time and detector response standards. Standards were chromatographed at the beginning and end of an analysis day to monitor column performance or detector response. The IR spectrophotometer was calibrated using polystyrene during each day of use. Calibration of the analytical balance was made using a set of NBS Class S quality weights before proceeding with any GRAV determinations.

Burdick and Jackson distilled in glass solvents (methanol, methylene chloride) were used to preextract the XAD-2 resin. All methylene chloride used for extraction purposes was prepared from the same manufacturer's lot. A blank of XAD-2 resin was prepared from the same manufacturer's lot and preextraction batch as the XAD-2 resin used in the actual SASS sampling run. This blank was taken to the field and exposed to the field lab conditions as was the actual sample. This XAD-2 blank subsequently was carried through all Level 1 analysis procedures used for the XAD-2 sample used in the SASS run, including LC fractionation and analysis. A methylene chloride blank volume greater or equal to that used for particulate and/or aqueous extractions was prepared from the solvent lot used for all analyses. The methylene chloride blank was carried through

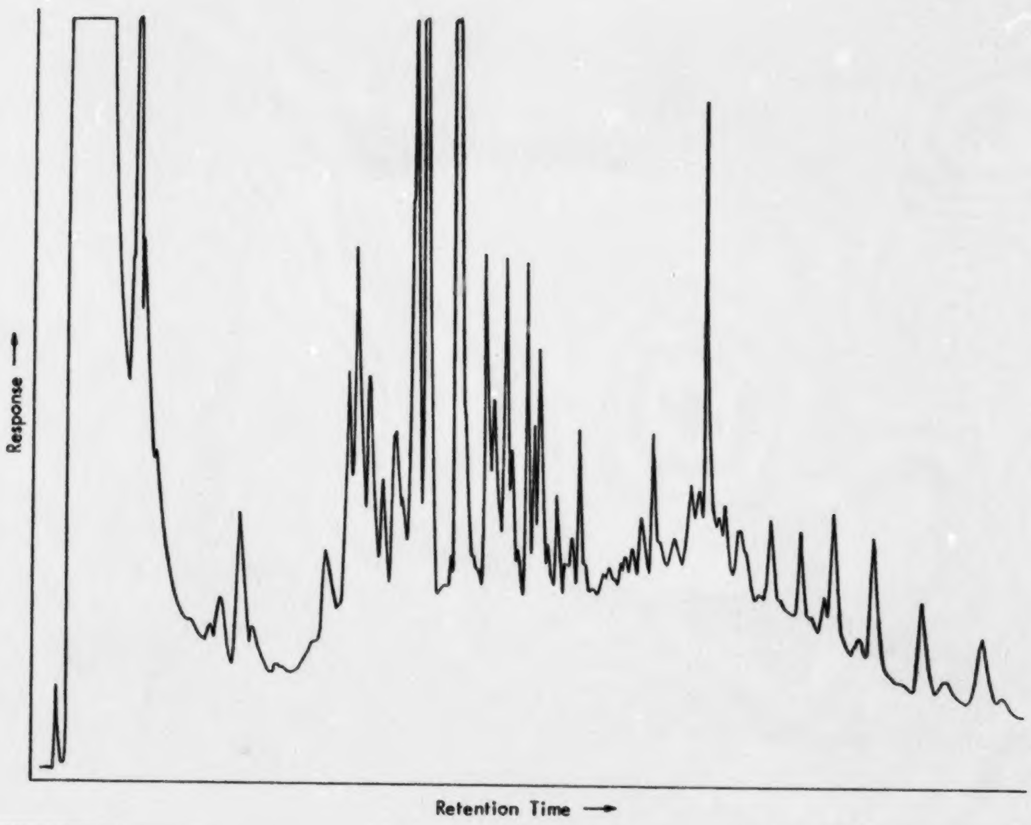


Figure A-8. Typical TCO chromatogram of concentrated extract from XAD-2 sample.

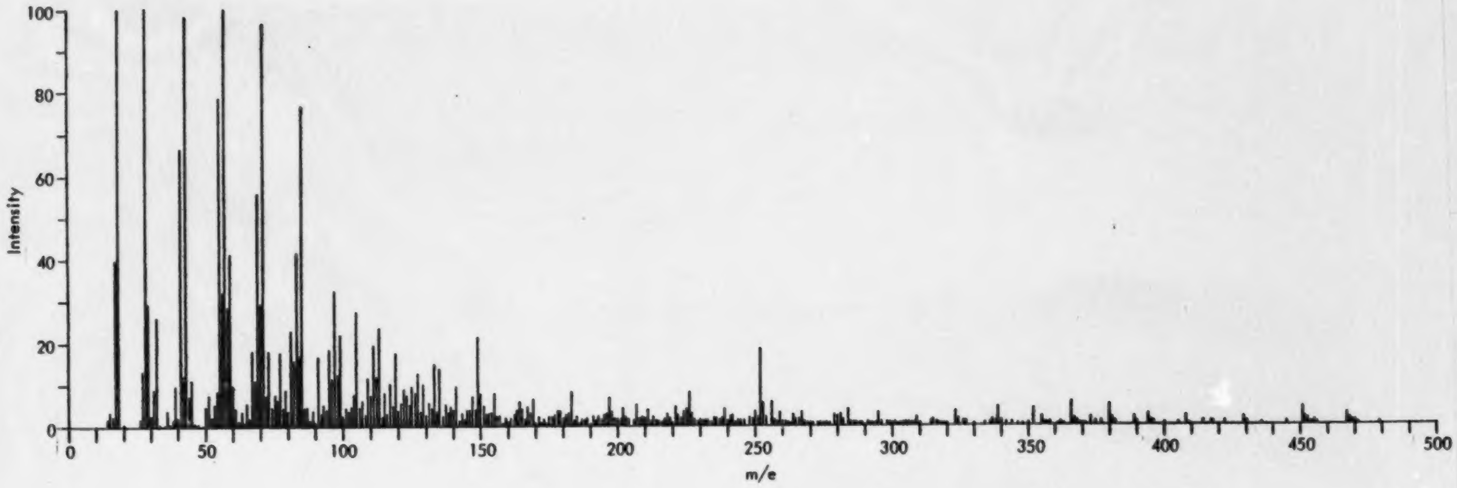


Figure A-9. Direct inlet LRMS of concentrated XAD-2 field sample extract.

all Level 1 analysis procedures including TCO, GRAV, and IR but not LC fractionation.

Problems

Generally insufficient material was present in GRAV residues to produce IR spectra of sufficient intensity for interpretation. This may be due to either the small absolute quantity of available material, the large number of components present, and/or some combination of these factors.

TCO chromatograms indicated the presence of a complex mixture of materials. It was found that a large number of the observed materials were excluded from the TCO analysis. This was a result of the limitation of the TCO analysis to those materials eluting earlier than C-17 carbon atom standard for the GC conditions used in the Level 1 protocol.

The analysis of both the XAD-2 resin field sample and field blank indicated a significant background level in both TCO and GRAV samples. Pretest TCO analysis of the XAD-2 resin had indicated the resin to be acceptably cleaned (according to Level 1 requirements). It would appear that background levels were encountered under either field lab or sample preparation conditions. Corrections for background levels were made to the TCO and GRAV values for XAD-2 resin when appropriate. Interpretation of direct inlet LRMS data was not attempted due to the large number of components observed in the TCO analysis, the spectral complexity, and the high background contribution observed in the XAD-2 blank.

The batch inlet LRMS analysis of the XAD-2 field sample was not performed. The exclusion of this analysis is based on the relative abundance of TCO materials ($\lesssim 0.05\%$ w/v) and the complexity of the mixture present as evidenced in the TCO analysis (> 50 components). Although the absolute quantity of the sample TCO material (5.6 mg) exceeds the Level 1 batch inlet LRMS requirements, previous experience has proven the inability to introduce sufficient sample material into the MS without solvent swamping problems.[1]

Reference

1. Golembiewski, M., K. Ananth, G. Trischan, and E. Baladi. Environmental Assessment of Waste-to-Energy Process: Braintree Municipal Incinerator. Final report.

APPENDIX B

SAMPLING LOCATIONS AND PROCEDURES

LOCATION OF SAMPLING POINTS

For this assessment program, samples of the following feed and effluent streams were taken:

- Wood chip feed;
- Fuel oil feed;
- Bottom ash discharge;
- Primary and secondary collector ash discharge;
- Boiler exhaust gases prior to the mechanical collectors; and
- Stack emissions after the collectors.

Specific sampling locations for each of these material streams are described below. Figure B-1 shows an overall view of the test site, including locations of the MRI field trailers and opacity observer locations.

Wood Fuel

Wood samples were taken from each of the four augers which feed Boiler No. 1 and composited at the end of each particulate run. Figure B-2 shows a typical feeder arrangement and the location from which the samples were obtained.

Oil Feed

Samples of the No. 2 fuel oil feed were drawn from an in-line valve which was located several feet upstream from the oil burners.

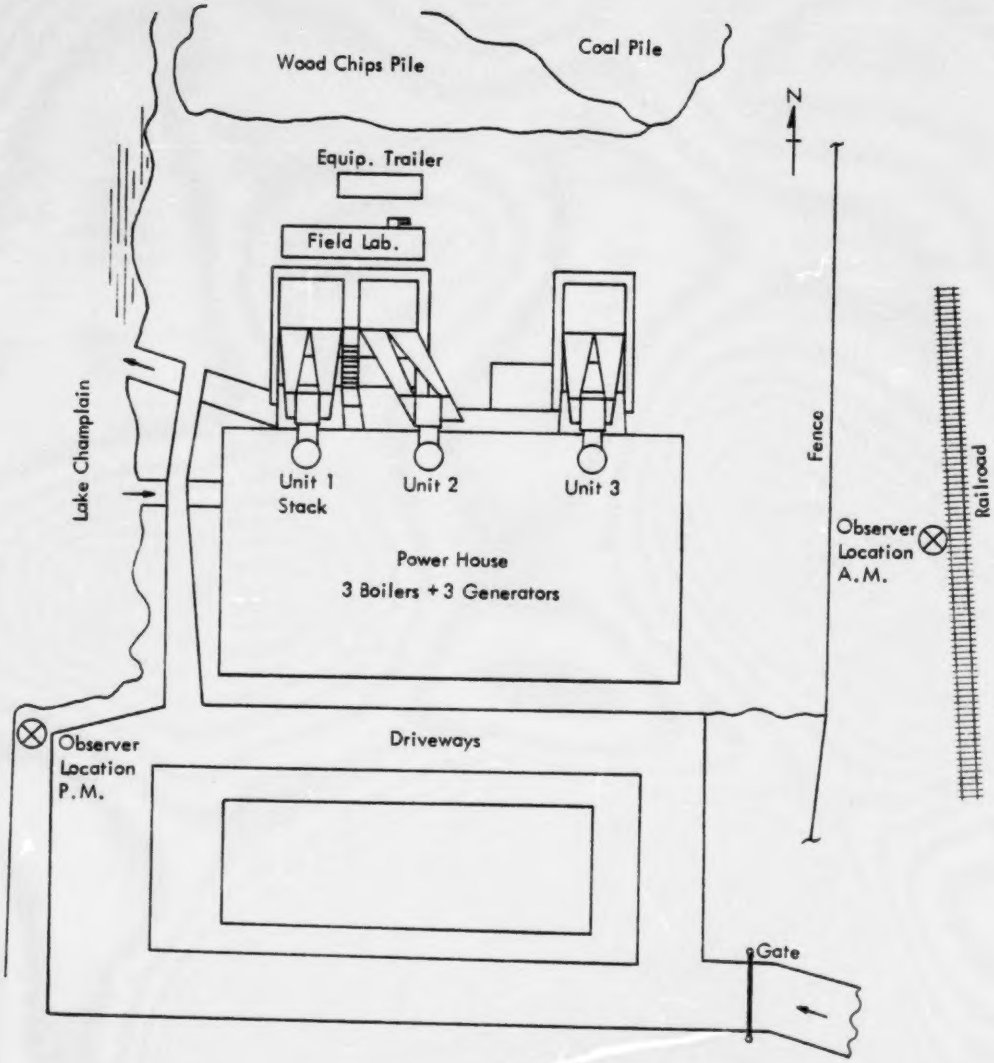

Wood Chips Pile
Coal Pile
N
Equip. Trailer
Field Lab.
Lake Champlain
Unit 1
Stack
Unit 2
Unit 3
Power House
3 Boilers + 3 Generators
Fence
Railroad
Observer
Location
A.M.
Driveways
Observer
Location
P.M.
Gate

Figure B-1. Layout of Burlington Electric Plant facilities.

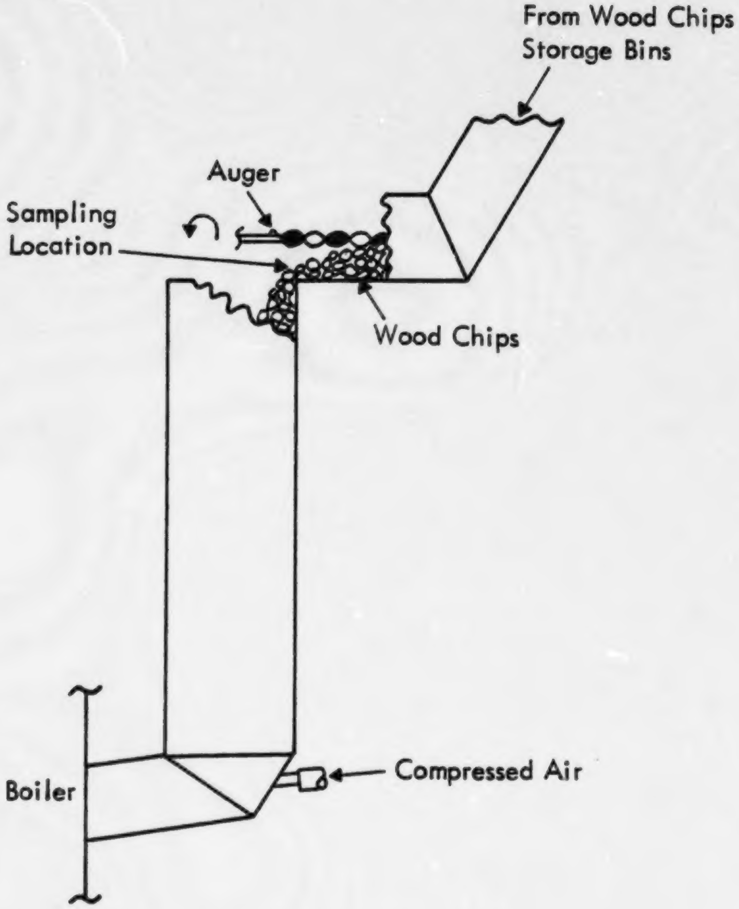

From Wood Chips
Storage Bins
Auger
Sampling
Location
Wood Chips
Compressed Air
Boiler

Figure B-2. Example of sampling location for wood feed stream.

Bottom Ash

Boiler bottom ash is discharged gravimetrically into two storage bins directly beneath the end of the stoker grate. Samples were collected via clean-out doors located at the base of each bin. Normally, these hoppers are emptied pneumatically and the ash is conveyed to a storage silo. But during the MRI tests, the pneumatic system was not operated to allow for the ash sampling.

Primary and Secondary Collector Ash

A schematic illustration of the primary and secondary collectors (and hoppers) is shown in Figure B-3. Separate samples were collected from each of the four hoppers (two per collector) at the conclusion of the test day, during physical removal of the collected ash. The pneumatic removal system was not in operation during the MRI test program.

Boiler Air Emissions Prior to Collector

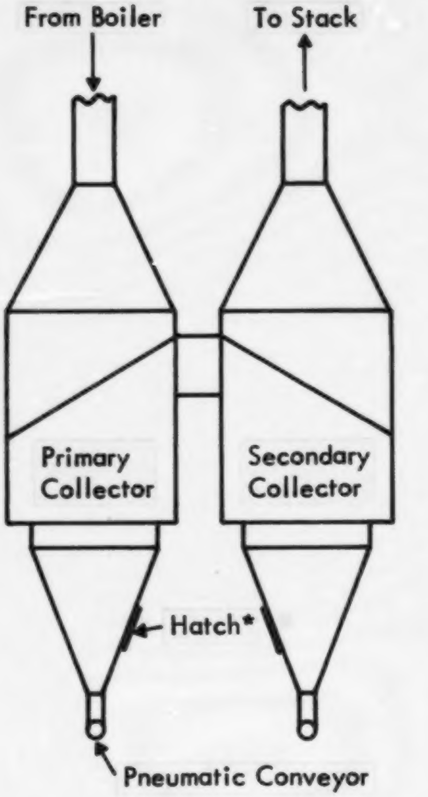
At this location, samples were taken for determination of total particulate concentration (EPA Method 5), gas analysis (Orsat) and particle size distribution. Figure B-4 is a schematic diagram showing the duct dimensions and locations of the individual sampling points. The nine sampling ports were 1.5 equivalent duct diameters downstream and 1.0 duct diameters upstream from the nearest flow disturbance, and were located in a plane perpendicular to the air flow. The number of traverse points (54) was determined according to EPA Method 1.

The particle size samples were drawn through a separate port at a point located 18 in. inside the duct (see Figure B-4).

Stack Emissions (After the Collector)

An illustration of the sampling location arrangement at the outlet of the collectors is shown in Figure B-5. The nine sampling ports were located 3.8 equivalent duct diameters downstream and 2.3 equivalent duct diameters upstream from the nearest flow disturbance. The 45 traverse points used in the Method 5 particulate sampling were determined according to EPA Method 1.

Particle size and SASS samples were taken at average velocity points through additional ports as shown in Figure B-5. The sampling point for the continuous analyzers was located deep inside the duct, about 4 ft upstream of the sampling ports. This minimized the possibility of air in-leakage and dilution of the sample stream going to the continuous monitors.


From Boiler
To Stack
Primary Collector
Secondary Collector
Hatch*
Pneumatic Conveyor

*Samples were drawn during the ash removal through the hatch.

Figure B-3. Illustration of the collector hopper arrangement.

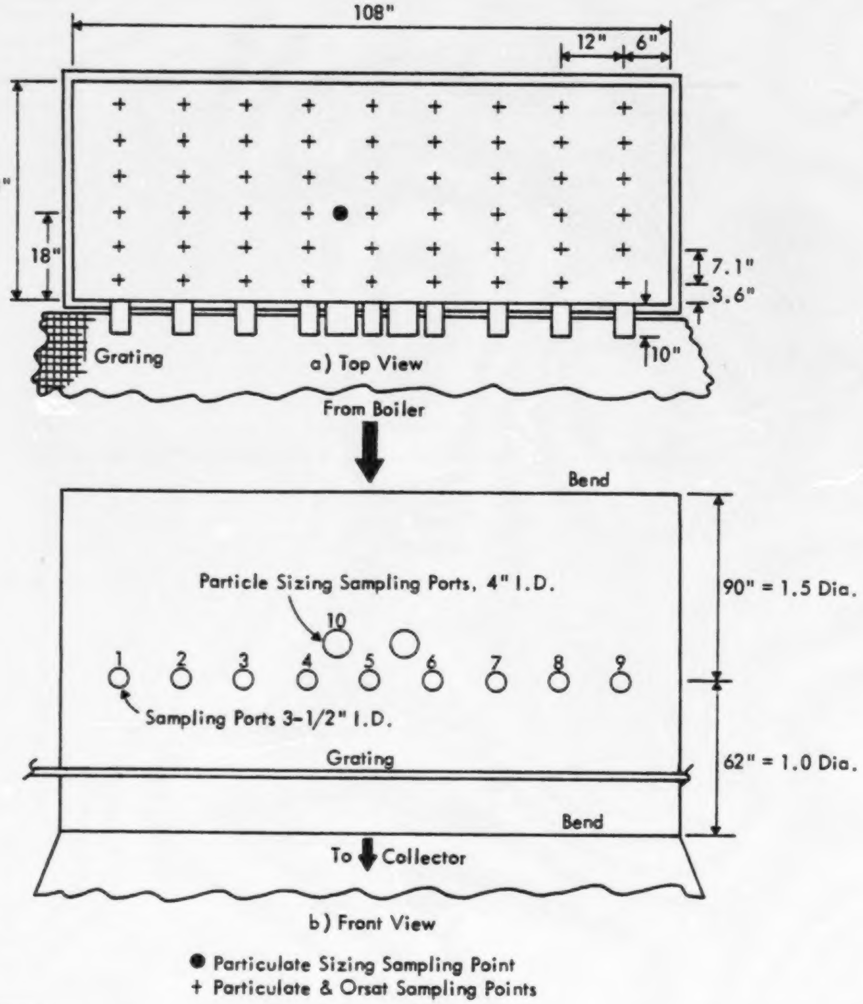

108"
12"
6"
43"
18"
7.1"
3.6"
10"
Grating
a) Top View
From Boiler
Bend
Particle Sizing Sampling Ports, 4" I.D.
10
1
2
3
4
5
6
7
8
9
90" = 1.5 Dia.
Sampling Ports 3-1/2" I.D.
Grating
62" = 1.0 Dia.
Bend
To Collector
b) Front View
● Particulate Sizing Sampling Point
+ Particulate & Orsat Sampling Points

Figure B-4. Schematic diagram of the inlet sampling location.

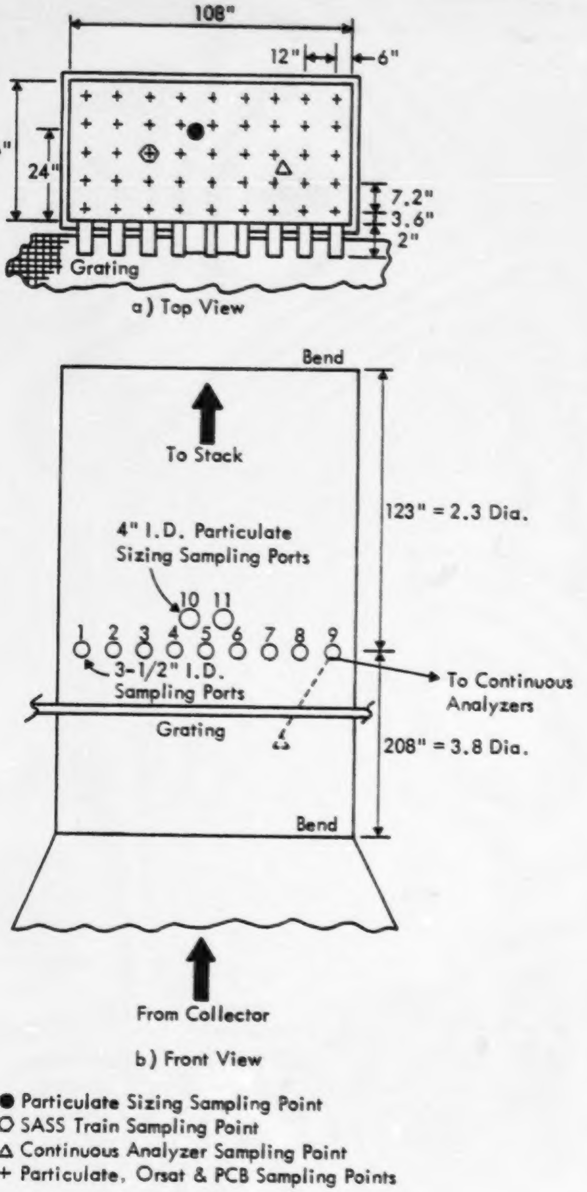

108"
12"
6"
36"
24"
7.2"
3.6"
2"
Grating
a) Top View
Bend
To Stack
123" = 2.3 Dia.
4" I.D. Particulate
Sizing Sampling Ports
10 11
1 2 3 4 5 6 7 8 9
3-1/2" I.D.
Sampling Ports
To Continuous
Analyzers
Grating
208" = 3.8 Dia.
Bend
From Collector
b) Front View
● Particulate Sizing Sampling Point
○ SASS Train Sampling Point
△ Continuous Analyzer Sampling Point
+ Particulate, Orsat & PCB Sampling Points

Figure B-5. Schematic diagram of the outlet sampling location.

SAMPLING AND GRAVIMETRIC ANALYTICAL PROCEDURES

Several sampling and analytical procedures were followed during the conduct of this study. All of these procedures are either approved, referenced, or recommended by EPA. Published EPA reference methods were followed whenever they were applicable.

Particulate Mass Concentration

EPA Methods 1 through 5 of the Federal Register (42:160, August 18, 1977; and 36:159, August 17, 1971) were followed in the sampling and analysis of particulate matter. Figure B-6 is a schematic illustration of the sampling train used.

Initial velocities, temperatures, and moisture contents of the flue gas were estimated from a previous compliance test report. The data from the initial estimate were used to preset the sampling equipment for the start of isokinetic sampling.

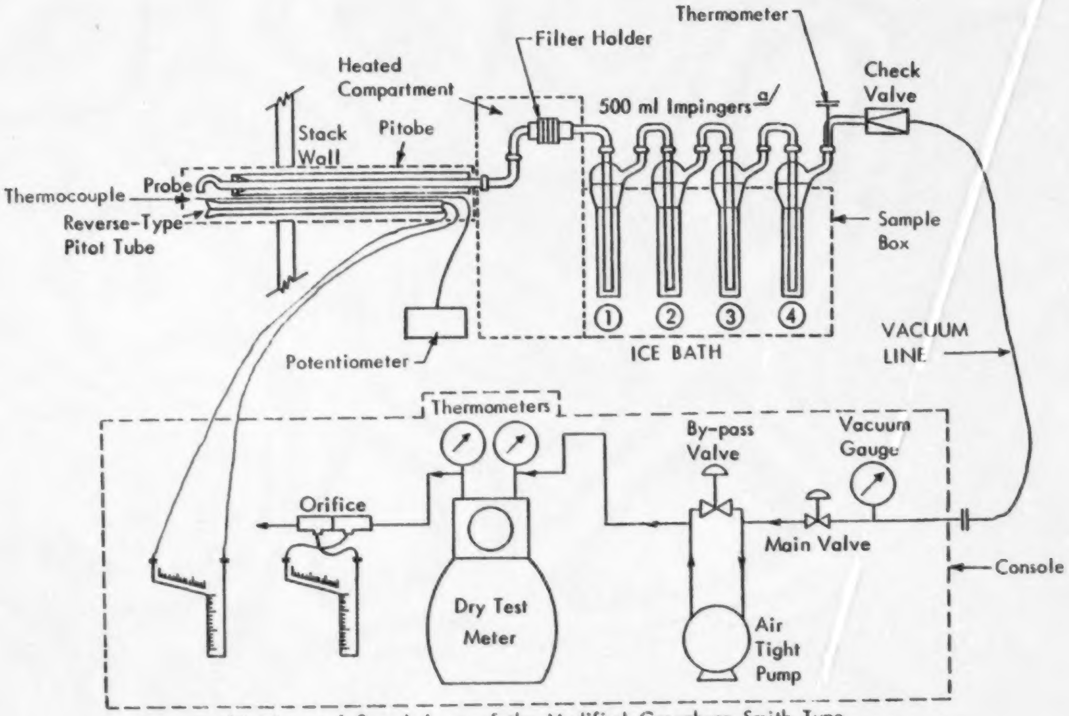
Particulate sampling and analysis were accomplished according to EPA Method 5 of the above mentioned Federal Register. Fifty-four traverse points were utilized to sample for particulate from the collector inlet duct. The sampling time at this inlet was 2 min/traverse point for a total of 108 min for each test. The collector outlet was divided into 45 traverse points for particulate sampling. The sampling time at the outlet was 2 min/traverse point for a total of 90 min for each test.

Particle Sizing

Particle size measurements were accomplished by utilizing the real-time particulate sizing system described below. MRI-established sampling procedures and the manufacturers' manuals were followed in conducting the tests.

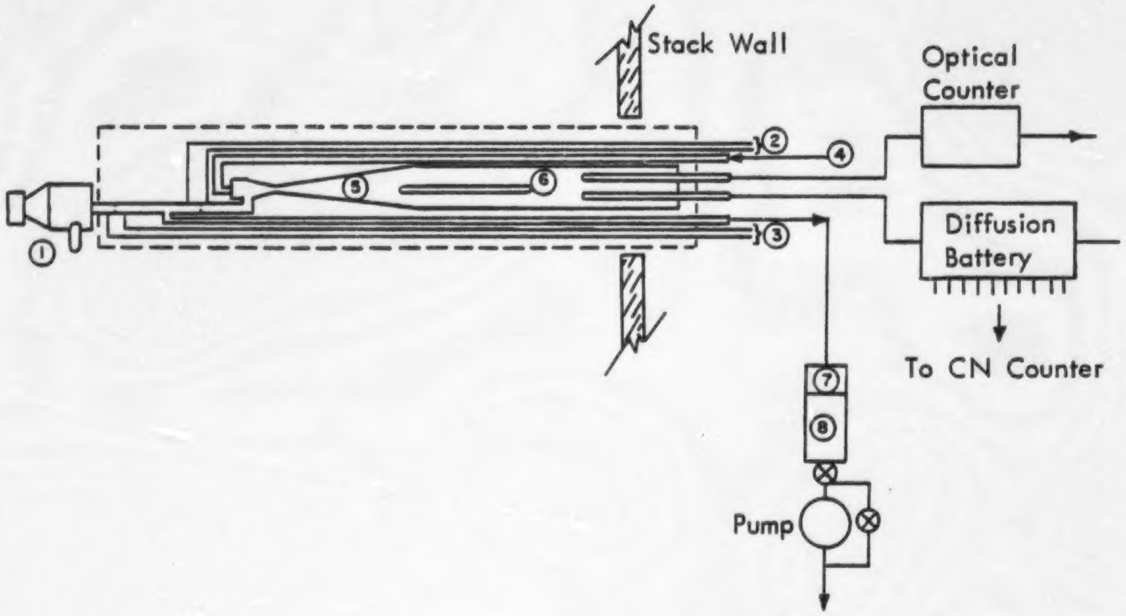
Two optical particle counters were used to count the number of particulate in the flue gas: the Climet Model 0208A optical counter, manufactured by Climet Instrument Company; and the GE Model 112 L428 G1 condensation nuclei counter, manufactured by General Electric Company. Since condensation nuclei counters count the total number of particles present in a stream, a diffusion battery was used to classify those particles into different sizes. The TSI Model 3040 diffusion battery, manufactured by Thermo-System, Inc., was used to classify the submicron particle sizes through the diffusion principle.

Optical counters are capable of measuring only low particle concentrations (ambient level); therefore, a dynamic dilution system, designed and fabricated by MRI, was incorporated in front of the counters to sample, dilute, and condition the sample continuously. Figure B-7 is a schematic illustration of the particle counter's sampling system used for this project. A photographic view


Thermometer
Filter Holder
Heated Compartment
Check Valve
500 ml Impingers a/
Stack Wall
Pitobe
Probe
Thermocouple
Reverse-Type Pitot Tube
Sample Box
1
2
3
4
ICE BATH
VACUUM LINE
Potentiometer
Thermometers
By-pass Valve
Vacuum Gauge
Orifice
Main Valve
Console
Dry Test Meter
Air Tight Pump

a/ Impingers 1,3 and 4 are of the Modified Greenburg-Smith Type
Impinger 2 is of the Greenburg-Smith Design
Impinger 1 and 2 Contain 100ml Water
Impinger 3 Empty
Impinger 4 Contains 200-300 Grams Silica Gel

Figure B-6. Schematic illustration of Method 5 sampling train in sampling position.


Stack Wall
Optical Counter
②
④
⑤
⑥
Diffusion Battery
①
③
To CN Counter
⑦
⑧
Pump

1-Cyclone (1.00 acfm, Particulate Cutoff Diameter 2.65μ)
2, 3-Flowrate Meters
4-Dried & Filtered Pressurized Air Supply
5-Dilutor
6-Neutralizer
7-Filter
8-Condenser

Figure B-7. Schematic illustration of the MRI dynamic dilution - optical counter particle sizing system.

of the dilution system is given in Figure B-8. Figure B-9 is a photographic view of the particle counting system in sampling position.

Continuous Monitoring for Gases

The continuous monitoring system for gases consisted of the following gas analyzers:

1. IBC O_2 analyzer (polarographic cell);
2. Bendix NO_x analyzer (chemiluminescent);
3. Beckman SO_2 analyzer (NDIR);
4. Beckman HC analyzer (NDIR); and
5. Beckman CO analyzer (NDIR).

The continuous monitoring system drew its sample from a common manifold. The sampling interface between the sampling point and the manifold, which is about 30 ft in length, consisted of a 1/4-in. heated Teflon tubing.

Analyzer manuals were followed in operating this continuous sampling system. Each monitor was connected to a strip chart recorder.

PCB/PAH Sampling System

Figure B-10 is a schematic diagram of the PCB/PAH train used for this project. The procedures published in the EPA environmental monitoring series (EPA-600/4-77-048, November 1977) were followed in sampling and analyzing for PCB pollutants. PAH analysis was conducted using MRI-established procedures.

Source Assessment Sampling System (SASS)

Operating procedures for the SASS train as published by EPA "Level 1 Environmental Assessment" (EPA-600/2-76-160a, June 1976 and subsequent modifications) were followed for these tests. This system is shown schematically in Figure B-11 in sampling position.

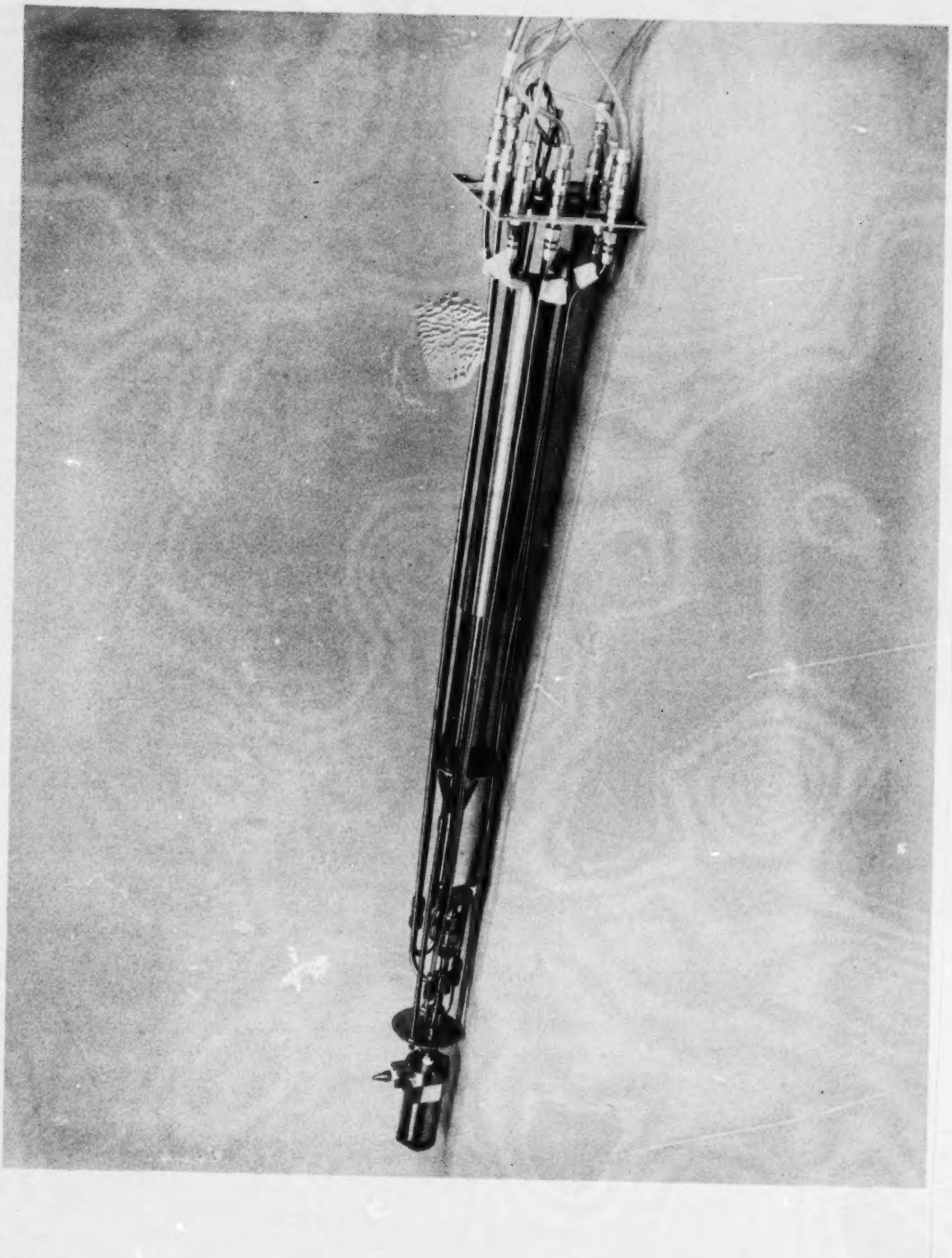


Figure B-8. Photograph of the MRI-developed dynamic dilution system.

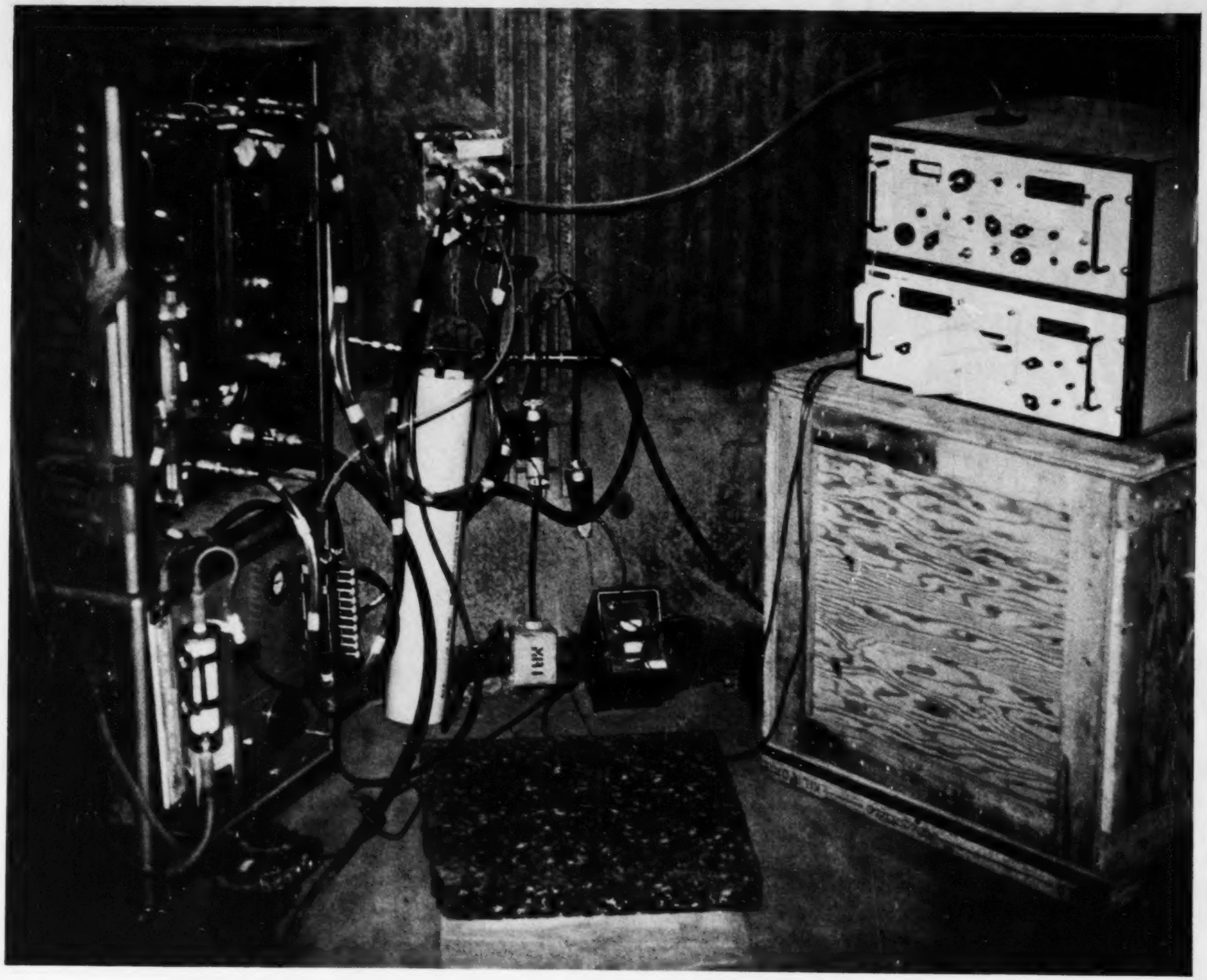


Figure B-9. Photograph of the particle counting system in sampling position.

Fig

Position

Sampling

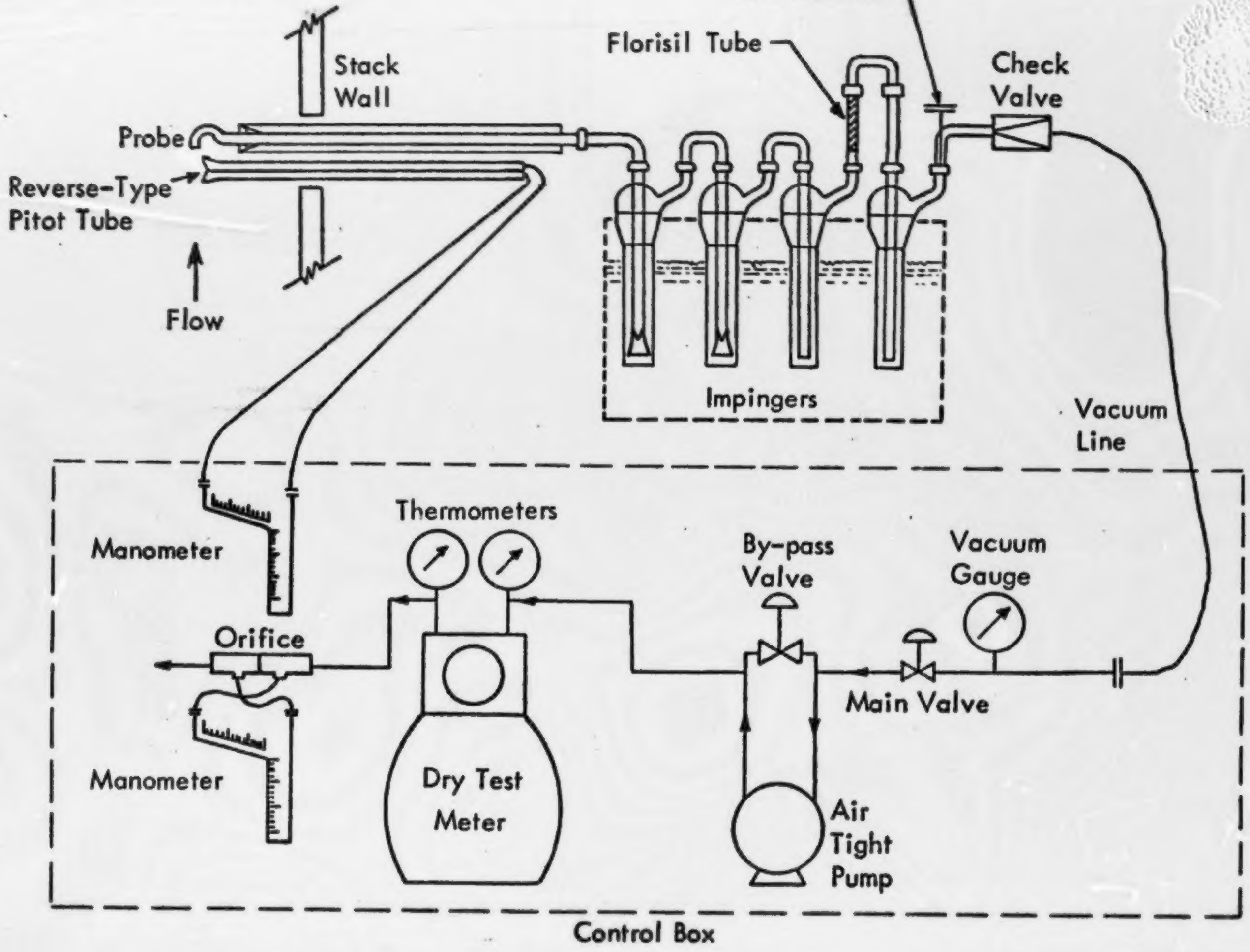
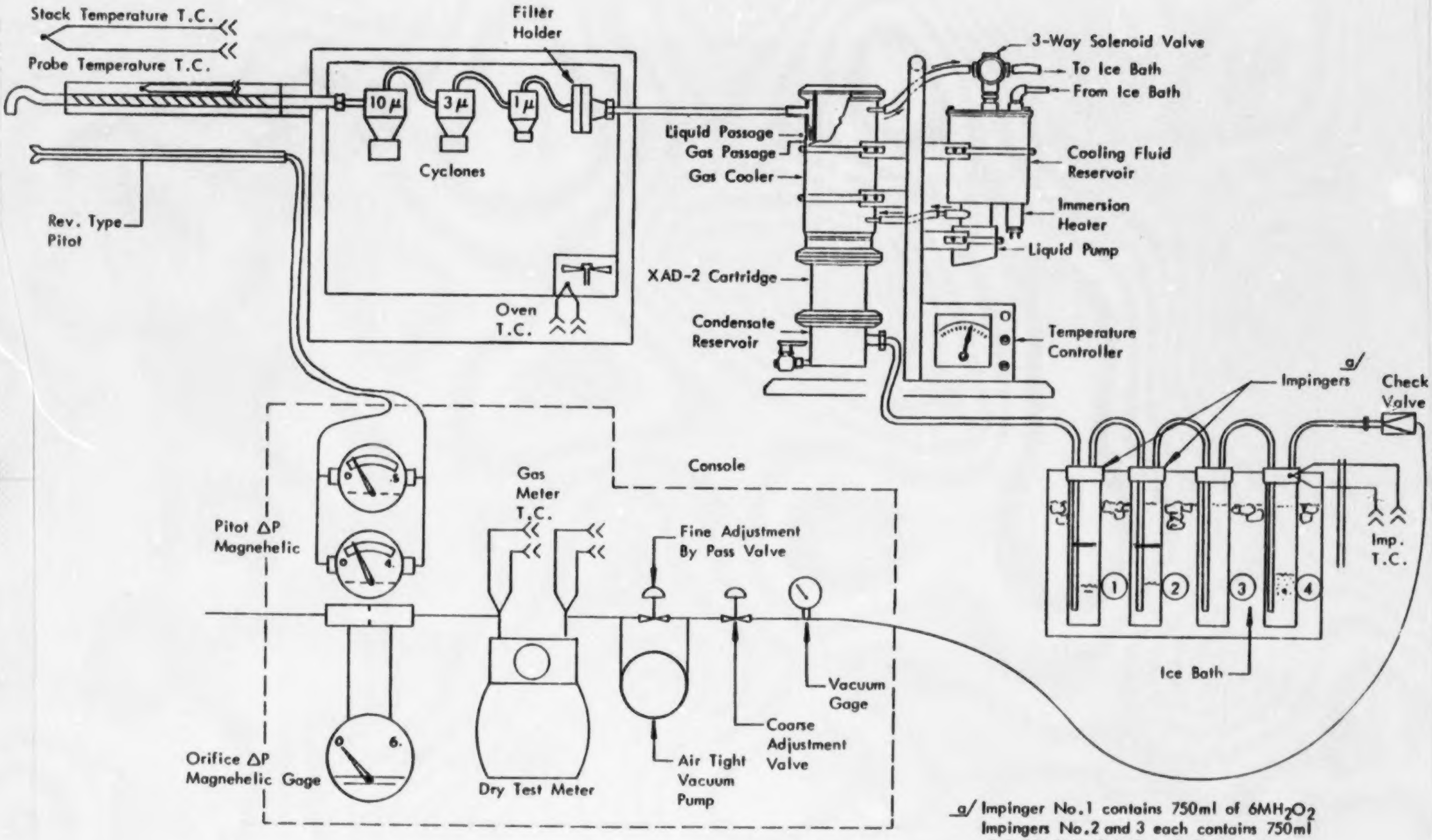

Stack Wall
Probe
Reverse-Type Pitot Tube
Flow
Florisil Tube
Thermometer
Check Valve
Impingers
Vacuum Line
Manometer
Thermometers
By-pass Valve
Vacuum Gauge
Orifice
Main Valve
Manometer
Dry Test Meter
Air Tight Pump
Control Box

Figure B-10. PCB sampling train.


Stack Temperature T.C.
Probe Temperature T.C.
Rev. Type Pitot
Filter Holder
10 μ
3 μ
1 μ
Cyclones
Oven T.C.
3-Way Solenoid Valve
To Ice Bath
From Ice Bath
Liquid Passage
Gas Passage
Gas Cooler
Cooling Fluid Reservoir
Immersion Heater
Liquid Pump
XAD-2 Cartridge
Condensate Reservoir
Temperature Controller
Impingers a/
Check Valve
1
2
3
4
Imp. T.C.
Ice Bath
Console
Pitot ΔP Magnehelic
Orifice ΔP Magnehelic Gage
Gas Meter T.C.
Dry Test Meter
Fine Adjustment By Pass Valve
Air Tight Vacuum Pump
Coarse Adjustment Valve
Vacuum Gage

a/ Impinger No.1 contains 750ml of $6MH_2O_2$
Impingers No.2 and 3 each contains 750ml of $0.2M\ (NH_4)_2S_2O_8 + 0.2M\ AgNO_3$
Impinger No.4 contains 750 grams Orierite

Figure B-11. Schematic diagram of the SASS train.

APPENDIX C

COMPARISON OF CHEMICAL ANALYSES OF BOTTOM ASH, PRIMARY ASH, AND SECONDARY COLLECTOR ASH

Chemical analyses of bottom ash, primary collector ash, and secondary collector ash have yielded data which may indicate significant differences between the various ash types. Prior to chemical analyses, bottom ash was ground to produce a powder; primary and secondary collector ashes were analyzed as received without grinding. The primary collector ash, which included fragments of charred wood, was found to be noticeably coarser than the secondary collector ash.

Analysis of PAH fortifications from the various ash matrices were highly variable as summarized in Table C-1. Recovery of PAH fortifications from the primary collector ash for a 5 ng/g fortification was generally less than 20% with the exceptions of acenaphthylene (35%) and fluorene (55%). Recoveries of a similar fortification from secondary collector ash were somewhat better for the earlier eluting PAH compounds fluoranthene (5 to 12%) and chrysene (0 to 10%). Detectable quantities of the later eluting PAH materials (benzo[a]pyrene, perylene, indeno[1,2,3-c,d]pyrene, 1,2,5,6-dibenzanthracene, and 1,12-benzoperylene) were not observed for the 5 ng/g fortification in either primary or secondary collector ash. As also shown in the table, the possibility of losses due to heating, handling, and/or simple surface interactions appears unlikely based on the recoveries of the same PAH materials from heated solvent and from ground bottom ash fortified at the 5 ng/g level and subsequently Soxhlet extracted. Analyses of 50 ng/g fortifications of the later eluting PAHs in primary and secondary ashes are summarized in Table C-2. The recovery of later eluting PAH compounds generally was low for both primary and secondary ash extracts.

The peculiar difference of primary collector ash from either bottom ash or secondary collector ash is illustrated in Figure C-1 (a, b, and c), which depicts the GC/MS reconstructed ion chromatograms (RIC) for the three ash types from a single test run. Figure C-1a illustrates the RIC of numerous compounds in a methylene chloride extract of bottom ash. In contrast, the RIC of primary collector ash which has been extracted and analyzed under the same conditions produces only two responses in addition to that of the internal standard, as shown in Figure C-1b.

TABLE C-1. QUALITY ASSURANCE DATA FOR LOW LEVEL PAH FORTIFICATION OF SELECTED SAMPLES

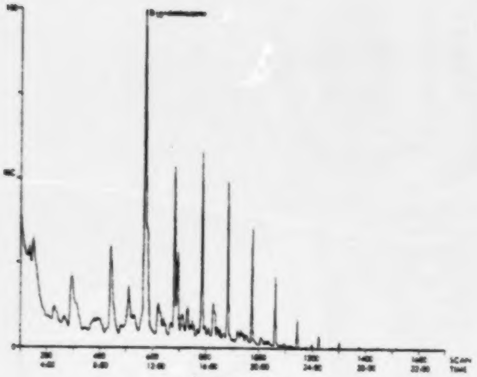
		Fortified solvent		Bottom ash		Primary collector ash		Secondary collector ash	
Compound	Total fortification quantity (µg)	Observed quantity (µg)	Recovery (%)	Observed quantitya/ (µg)	Recovery (%)	Observed quantitya/ (µg)	Recovery (%)	Observed quantitya/ (µg)	Recovery (%)
Acenaphthylene	187.8	116.8	62	94.8	51	65.8	35	84.9	45
Fluorene	185.3	134.1	72	103.9	56	101	55	142	77
Phenanthrene	162.1	129.0	80	111.2	69	24.5	15	104b/	64b/
Anthracene	131.1	106.4	81	57.4	44	9.67	7	99.0	75
Fluoranthene	146.7	142.6	97	87.4	60	7.95	5	18.2b/	12b/
Pyrene	123.1	118.6	96	75.3	61	6.11	5	42.6b/	35b/
Chrysene	95.5	106.0	111	77.0	81	0	0	9.6	10
1,2-Benzanthracene	133.5	133.7	100	39.7	30	1.45	1	10.3b/	8b/
Benzo[a]pyrene	135.8	146.0	108	53.0	39	0	0	0	0
Perylene	73.7	86.5	117	35.3	48	0	0	0	0
Indeno[1,2,3-c,d]pyrene	129.3	183.6	142	61.0	47	0	0	0	0
1,2,5,6-Dibenzanthracene	112.0	164.6	147	41.6	37	0	0	0	0
1,12-Benzoperylene	79.1	109.2	138	44.0	56	0	0	0	0

a/ Values corrected to D-10 anthracene internal standard.

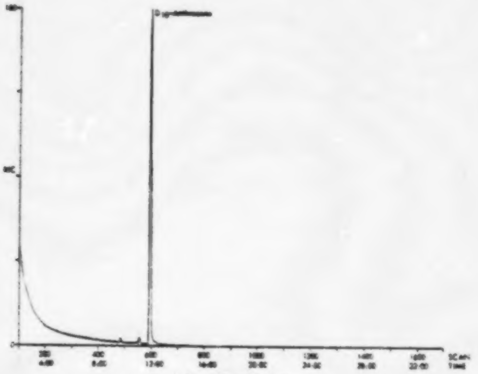
b/ Values corrected for sample contribution.

TABLE C-2. GC/MS QUALITY ASSURANCE DATA FOR SELECTED LONG RETENTION TIME PAH COMPOUNDS

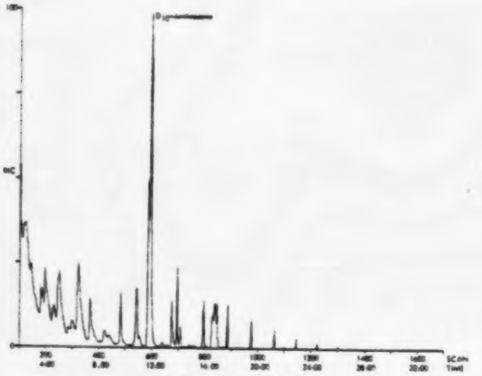
Compound	Total fortification quantity (μg)	Primary collector ash Observed quantity (μg)	Primary collector ash Recovery (%)	Secondary collector ash Observed quantity (μg)	Secondary collector ash Recovery (%)
Chrysene	1,162	92.2	8	71.8	6
1,2-Benzanthracene	1,202	205	17	181	15
Benzo[a]pyrene	1,328	58.0	4	46.4	3
Perylene	826	44.8	5	34.9	4
Indeno[1,2,3-c,d]pyrene	1,320	4.6	0.4	32.5	2
1,2,5,6-Dibenzanthracene	763	0	0	0	0
1,12-Benzoperylene	1,256	18.1	1	21.8	2



a. Ground Bottom Ash Extract



b. Primary Collector Ash Extract



c. Secondary Collector Ash Extract

Figure C-1. GC/MS chromatograms for bottom ash, primary collector ash, and secondary collector ash extracts.

Finally, Figure C-1c presents the RIC of secondary collector ash extract which contains numerous components and appears very comparable to the bottom ash extract. From these observations, it is evident that either organic material is absent from the primary collector ash or the organic material is not efficiently extracted. The observation of strongly colored extracts observed from secondary and bottom ash in contrast to the pale yellow to colorless extracts observed from primary ash further reinforces the conclusions. Additional aliquots of primary collector ash were extracted with similar visual and GC/MS results.

A similarly unexpected phenomenon was observed during the analyses of extracts from ash samples which had been fortified with Arochlor 1254 PCB material. As discussed in the quality assurance section, recovery of Arochlor 1254 fortifications from both bottom ash and secondary collector ash were on the order of 100%. In the case of fortified primary collector ash, certain PCB compounds were found to be selectively absent from the characteristic Arochlor 1254 patterns. The selectively absent compounds were not found to be related to a particular number of chlorine atoms per molecule; losses of di-, tri-, tetra-, and pentachlorinated biphenyls were found. The presence of a strongly absorptive/adsorptive material in the primary collector ash is strongly suggested by these results.

Comparison of averaged SSMS data for the series of duplicate ash analyses provides some additional information. Although many analyses were within an order of magnitude, primary collector ash generally was found to contain low or intermediate component concentrations for many elements. Secondary collector ash was generally found to contain intermediate to high component concentrations compared to primary collector ash. Bottom ash was most frequently found to contain elemental concentrations between the levels observed for primary and secondary ashes. It was also noted that several of the more volatile elements, e.g., Hg, As, Se, Br, and F, appeared to be successively enriched from bottom ash through primary collector ash and secondary collector ash. It cannot be determined from the SSMS data whether the primary collector ash contains significantly different proportions of major constituents, such as carbon or silicon, when compared to bottom ash or secondary collector ash because in all cases these elements are identified as major components in the SSMS results.

To investigate the presence of major differences in the particulate which could be expected between carbonaceous and silicate materials, a crude density gradient experiment was performed on the three ash types. A density range of 1.6 to 2.8 g/ml was found using carbon tetrachloride and tetrabromoethane in varying proportions. The differences in the effective densities of ground bottom ash, primary collector ash, and secondary collector ash are illustrated in Figure C-2. The bulk of the ground bottom ash is observed in the higher density regions above a density of 2.4 g/ml. This would be expected of a silicate material. The primary collector ash is found to contain particles having

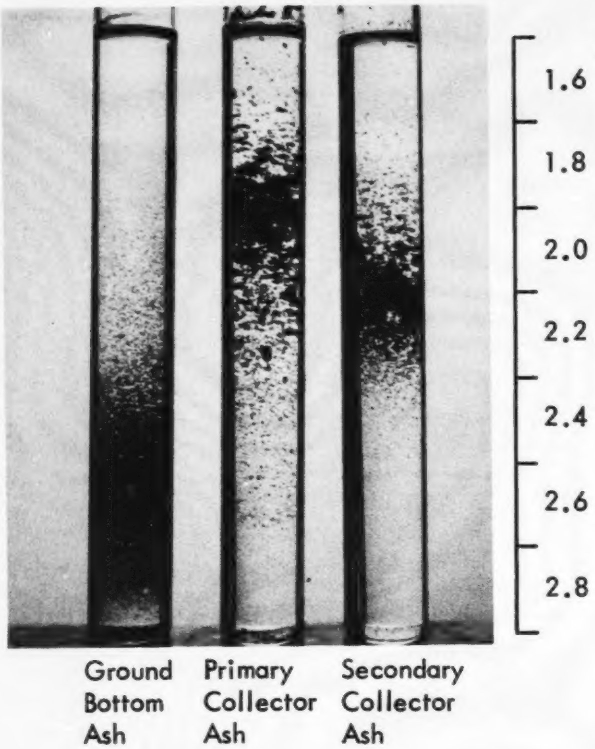

1.6
1.8
2.0
2.2
2.4
2.6
2.8
Ground Bottom Ash
Primary Collector Ash
Secondary Collector Ash

Figure C-2. Photo of density gradient experiment.

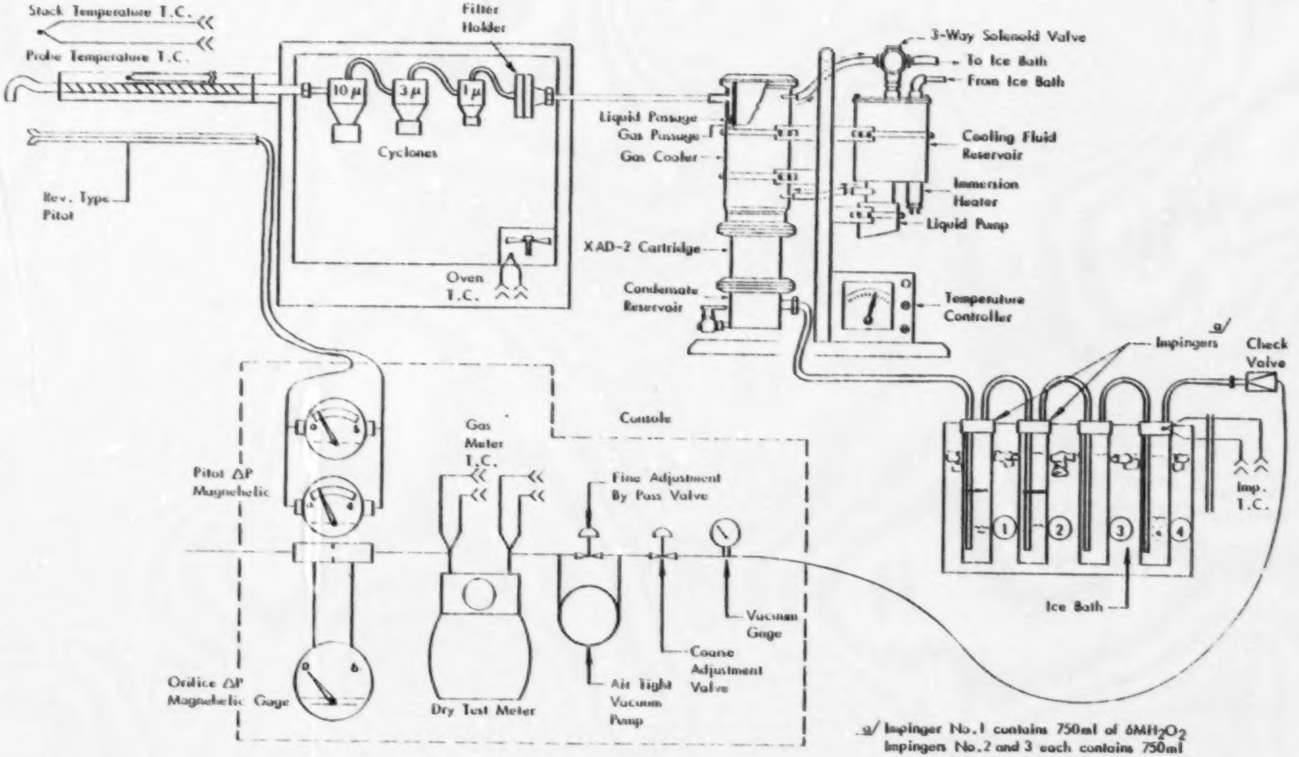
widely variable effective densities. However, the bulk of the primary collector ash is less dense than either the bottom ash or secondary collector ashes. The relatively uniform intermediate density of secondary collector ash is also illustrated. During the course of this experiment the presence of relatively large particulates resembling charred wood were also noted in the primary collector ash. It appears that the most significant sources of difference between the solid materials tested which may affect sample extraction and analysis are major component composition and associated physical properties, as evidenced by the observed differences in effective particle density.

APPENDIX D

DESCRIPTION OF SASS EQUIPMENT AND ANALYSIS

The SASS is a method prescribed by EPA for environmental assessment work. It is somewhat similar to, but more complex than, the EPA Method 5 train. Basic components of the SASS train are shown in Figure D-1. It is different from the Method 5 train in that the filter is preceded by three cyclones and the filter is followed by an XAD-2 cartridge for collection of organics. Also, the impingers contained special solutions for collection of vaporous metals (e.g., Hg).

Analysis of the SASS train components, as prescribed by EPA's Level 1 environmental assessment procedure, is quite complex. A tabular presentation of the required analysis is shown in Table D-1. This matrix is in accordance with a Level 1 assessment, with the exception of morphology and bioassay. However, for the purposes of this test program, MRI has added certain other analyses as indicated in Table D-1.


Stack Temperature T.C.
Probe Temperature T.C.
Rev. Type Pitot
Filter Holder
10 μ
3 μ
1 μ
Cyclones
Oven T.C.
Liquid Passage
Gas Passage
Gas Cooler
XAD-2 Cartridge
Condensate Reservoir
3-Way Solenoid Valve
To Ice Bath
From Ice Bath
Cooling Fluid Reservoir
Immersion Heater
Liquid Pump
Temperature Controller
a/ Impingers
Check Valve
1
2
3
4
Imp. T.C.
Ice Bath
Console
Pitot ΔP Magnehelic
Orifice ΔP Magnehelic Gage
Gas Meter T.C.
Dry Test Meter
Fine Adjustment By Pass Valve
Air Tight Vacuum Pump
Coarse Adjustment Valve
Vacuum Gage

a/ Impinger No.1 contains 750ml of $6M H_2O_2$
Impingers No.2 and 3 each contains 750ml
of 0.2M $(NH_4)_2S_2O_8$ + 0.2M $AgNO_3$
Impinger No.4 contains 750 grams Drierite

Figure D-1. Schematic of source assessment sampling system.

TABLE D-1. ANALYSIS MATRIX FOR SASS TRAIN COMPONENTS

	Particulate							
	Probe and cyclone rinse	10 µm	3 µm	1 µm	Filter	XAD-2 resin	Aqueous condensate	Impinger solutions
			EPA Level 1 protocol					
SSMS							X	X[a]
Hg by atomic absorption							X	X
			Combined					
CH_2Cl_2 extraction								
Gravimetric	X		X			X	X	
IR analysis			X			X		
LRMS analysis			X			X		
LC (7 fractions)			X			X		
			Additional analyses selected by MRI					
PCB material				X		X	X	
PAH compounds				X		X	X	

[a] Hydrogen peroxide impinger only.

APPENDIX E

DATA TABLES FOR SAM-1A

TABLE E-1. SAM-1A SUMMARY SHEET

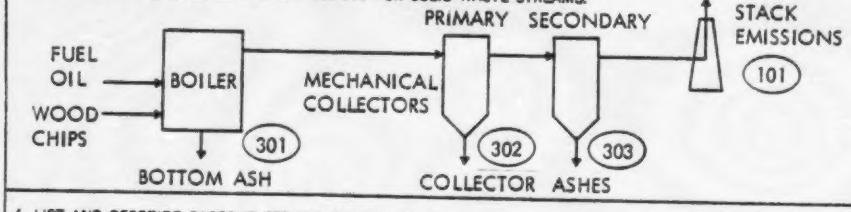
Form IA01

1. SOURCE AND APPLICABLE CONTROL OPTIONS

BURLINGTON ELECTRIC DEPARTMENT WOOD AND OIL FIRED BOILER

2. PROCESS THROUGHPUT OR CAPACITY 10 MW (100,000 lb steam per hour)

3. USE THIS SPACE TO SKETCH A BLOCK DIAGRAM OF THE SOURCE AND CONTROL ITEMS SHOWING ALL EFFLUENT STREAMS. INDICATE EACH STREAM WITH A CIRCLED NUMBER USING 101-199 FOR GASEOUS STREAMS, 201-299 FOR LIQUID STREAMS, AND 301-399 FOR SOLID WASTE STREAMS.


PRIMARY
SECONDARY
STACK EMISSIONS
101
FUEL OIL
WOOD CHIPS
BOILER
MECHANICAL COLLECTORS
301
302
303
BOTTOM ASH
COLLECTOR ASHES

4. LIST AND DESCRIBE GASEOUS EFFLUENT STREAMS USING RELEVANT NUMBERS FROM STEP 3.

101 Stack Emissions (after mechanical collectors)
102
103
104
105
106
107

5. LIST AND DESCRIBE LIQUID EFFLUENT STREAMS USING RELEVANT NUMBERS FROM STEP 3.

201
202
203
204
205
206

6. LIST AND DESCRIBE SOLID WASTE EFFLUENT STREAMS USING RELEVANT NUMBERS FROM STEP 3.

301 Bottom ash
302 Primary collector ash
303 Secondary collector ash
304
305
306

7. IF YOU ARE PERFORMING A LEVEL 1 ASSESSMENT, COMPLETE THE IA02-LEVEL 1 FORM FOR EACH EFFLUENT STREAM LISTED ABOVE. IF YOU ARE PERFORMING A LEVEL 2 ASSESSMENT, COMPLETE THE IA02-LEVEL 2 FORM FOR EACH EFFLUENT STREAM LISTED ABOVE.

TABLE E-1. (continued)

8. LIST SUMS FROM LINE 7, FORMS IA02, IN TABLE BELOW

DEGREE OF HAZARD AND TOXIC UNIT DISCHARGE RATES BY EFFLUENT STREAM

GASEOUS					LIQUID					SOLID WASTE				
STREAM CODE	DEGREE OF HAZARD		TOXIC UNIT DISCHARGE RATES		STREAM CODE	DEGREE OF HAZARD		TOXIC UNIT DISCHARGE RATES		STREAM CODE	DEGREE OF HAZARD		TOXIC UNIT DISCHARGE RATES	
	HEALTH BASED	ECOL BASED	HEALTH BASED	ECOL BASED		HEALTH BASED	ECOL BASED	HEALTH BASED	ECOL BASED		HEALTH BASED	ECOL BASED	HEALTH BASED	ECOL BASED
	–	–	(m^3/sec)			–	–	(l/sec)			–	–	(g/sec)	
101	1.8E2	1.6E1	3.8E3	3.3E2						301	4.4E3	1.0E6	1.1E5	2.6E7
										302	2.1E3	1.0E6	1.2E5	5.7E7
										303	7.0E3	1.1E6	1.1E4	1.7E6
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O

9. SUM SEPARATELY GASEOUS, LIQUID AND SOLID WASTE STREAM DEGREES OF HAZARD FROM TABLE AT LINE 8 (I.E., SUM COLUMNS)

TOTAL DEGREE OF HAZARD

	HEALTH-BASED	ECOLOGICAL-BASED
GASEOUS	(Σ COL. B) 9A 1.79E2	(Σ COL. C) 9A' 1.59E1
LIQUID	(Σ COL. G) 9B –	(Σ COL. H) 9B' –
SOLID WASTE	(Σ COL. L) 9C 1.34E4	(Σ COL. M) 9C' 3.1E6

10. SUM SEPARATELY GASEOUS, LIQUID AND SOLID WASTE STREAM TOXIC UNIT DISCHARGE RATES FROM TABLE AT LINE 8 (I.E., SUM COLUMNS)

TOTAL TOXIC UNIT DISCHARGE RATES

	HEALTH-BASED	ECOLOGICAL-BASED
GASEOUS (m^3/sec)	(Σ COL. D) 10A 3.76E3	(Σ COL. E) 10A' 3.34E2
LIQUID (l/sec)	(Σ COL. I) 10B –	(Σ COL. J) 10B' –
SOLID WASTE (g/sec)	(Σ COL. N) 10C 2.41E5	(Σ COL. O) 10C' 8.47E7

11. NUMBER OF EFFLUENT STREAMS

GASEOUS	11A	1
LIQUID	11B	0
SOLID WASTE	11C	3

12. LIST POLLUTANT SPECIES KNOWN OR SUSPECTED TO BE EMITTED FOR WHICH A MATE IS NOT AVAILABLE.

146

SAM/IA WORKSHEET FOR LEVEL 1

TABLE E-2. BOTTOM ASH WORKSHEET

Form IA02 Level 1

Page 1 / 3

1. SOURCE/CONTROL OPTION

Burlington Electric Wood and Oil Fired Boiler

2. EFFLUENT STREAM

301 — CODE #
Bottom Ash — NAME

3. EFFLUENT STREAM FLOW RATE

Q = 25.2 g/sec

(gas = m³/sec — liquid = l/sec — solid waste = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ if HEALTH MATE EXCEEDED	√ if ECOL MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE (HEALTH BASED) (E × LINE 3)	TOXIC UNIT DISCHARGE RATE (ECOLOGICAL BASED) (G × LINE 3)
UNITS	µg/g	µg/g	µg/g	—	—	—	—	—	—	g/sec	g/sec
SSMS											
27/Li	590	0.70	0.75	843		787		✓	✓	2.12E4	1.98E4
28/Na	>1,000	1.63E3	N	>0.6		-				>1.51E1	-
29/K	>1,000	N	N	-		-				-	-
30/Rb	96	3.6E3	N	0.03		-				0.76	-
31/Ge	5	2.5E3	N	0.002		-				0.05	-
32/Be	7	0.06	0.11	117		64		✓	✓	2.95E3	1.61E3
33/Mg	>1,000	1.8E2	1.7E2	>5.6		>5.9		✓	✓	>1.41E2	>1.49E2
34/Ca	>1,000	4.8E2	e.2E1	>2.1		>31		✓	✓	>5.29E1	>7.81E2
35/Sr	>800	9.2E1	N	>8.7		-		✓	✓	>2.19E2	-
36/Ba	>1,000	1.0E1	5.0	>10		>500		✓	✓	>2.52E2	>1.26E4
37/B	72	9.3E1	5.0E1	0.8		1.4			✓	2.02E1	3.53E1
38/Al	>1,000	1.6E2	2.0	>6.3		>500		✓	✓	>1.59E2	>1.26E4
39/Ga	48	1.5E2	N	0.3		-				7.6	-

If MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD
HEALTH MATE BASED (Σ COL. E) 5a 5.355E3
ECOLOGICAL MATE BASED (Σ COL. G) 5b 1.016E6
(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF ENTRIES COMPARED TO MATES
HEALTH 6a ____
ECOLOGICAL 6b ____

7. TOXIC UNIT DISCHARGE SUM
HEALTH MATE BASED (Σ COL. K) 7a 1.097E5
ECOLOGICAL MATE BASED (Σ COL. L) 7b 2.559E7
(ENTER HERE AND AT LINE 8, FORM IA01)

TABLE E-2. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

Page 2 / 3

SOURCE/CONTROL OPTION Burlington

EFFLUENT STREAM NO 301

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (G x LINE 3)
UNITS	µg/g	µg/g	µg/g	—	—	—	—	—	—	g/sec	g/sec
40/In	Internal	Standard		-		-				-	-
41/Tl	≤0.7	3.0	N	≤0.2		-				≤5.0	-
42/C	Not reported			-		-				-	-
43/Si	>1,000	3.0E2	N	>3.3		-		✓		>8.32E1	-
44/Ge	4	1.7E1	N	0.2		-				5.0	-
45/Sn	2	N	N	-		-				-	-
46/Pb	5	0.50	0.10	10		50		✓	✓	2.52E2	1.26E3
48/Pb	>1,000	3.0E1	0.001	>33		>1.0E6		✓	✓	>8.32E2	>2.52E7
49/As	15	0.50	0.10	30		15		✓	✓	7.56E2	3.78E2
50/Sb	2	1.5E1	0.40	0.1		5			✓	2.5	1.26E2
51/Bi	<0.2	1.2E1	N	<0.02		-				<0.5	-
53/S	>1,000	N	N	-		-				-	-
54/Se	2	0.10	0.05	20		40		✓	✓	5.04E2	1.0E3
55/Te	<0.2	3.0	N	<0.07		-				<1.8	-
56/F	156	7.5E1	N	2.1		-		✓		5.29E1	-
57/Cl	35	2.6E3	N	0.01		-				0.25	-
58/Br	2	N	N	-		-				-	-
59/I	<0.2	N	N	-		-				-	-
60/Sc	48	1.6E3	N	0.03		-				0.76	-
61/Y	94	3.0E1	N	3.1		-		✓		7.81E1	-
62/Ti	>1,000	1.8E2	N	>5.6		-		✓		>1.41E2	-
63/Zr	265	1.5E1	N	18		-		✓		4.54E2	-
64/Hf	3	1.5	N	2		-		✓		50	-
65/V	250	5.0	0.30	50		833		✓	✓	1.26E3	2.10E4
66/Nb	47	6.5E2	N	0.07		-				1.8	-

TABLE E-2. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1 Page 3 / 3

SOURCE/CONTROL OPTION Burlington EFFLUENT STREAM NO 301

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E × LINE 3)	(ECOLOGICAL BASED) (G × LINE 3)
UNITS	μg/g	μg/g	μg/g	—	—	—	—	—	—	g/sec	g/sec
67/Ta	<0.2	1.5E2	N	<0.001		-				<0.003	-
68/Cr	310	0.50	0.50	620		620		✓	✓	1.56E4	1.56E4
69/Mo	9	1.5E2	1.4E1	0.06		0.6				1.5	15
70/W	2	3.0E1	N	0.07		-				1.8	-
71/Mn	>1,000	0.50	0.20	>2,000		>5,000		✓	✓	>5.04E4	>1.26E5
72/Fe	>1,000	3.0	0.50	>333		>2,000		✓	✓	>8.39E3	>5.04E4
73/Ru	<0.2	N	N	-		-				-	-
74/Co	34	1.5	0.50	23		68		✓	✓	5.80E2	1.71E3
75/Rh	<0.2	0.03	N	<6.7		-		✓		<1.69E2	-
76/Ni	80	0.45	0.02	178		4,000		✓	✓	4.49E3	1.01E5
77/Pt	<0.2	0.06	N	<3.3		-		✓		<8.32E1	-
78/Cu	85	1.0E1	0.10	8.5		850		✓	✓	2.14E2	2.14E4
79/Ag	0.3	0.50	0.10	0.6		3			✓	15	7.56E1
80/Au	<0.2	N	N	-		-				-	-
81/Zn	74	5.0E1	0.20	1.5		37		✓	✓	3.78E1	9.32E2
82/Cd	≤0.4	0.10	0.002	≤4		200		✓	✓	≤1.01E2	5.04E3
83/Hg	0.09	0.02	0.50	4.5		0.2		✓		1.13E2	5.0
84/La	57	3.4E3	N	0.002		-				0.05	-

TABLE E-3. PRIMARY COLLECTOR ASH WORKSHEET

SAM/IA WORKSHEET FOR LEVEL 1

Form IA02 Level 1

Page 1 / 3

1. SOURCE/CONTROL OPTION

Burlington Electric Wood and Oil Fired Boiler

2. EFFLUENT STREAM

302 (CODE #) Primary Collector Ash (NAME)

3. EFFLUENT STREAM FLOW RATE

Q = 55.8 g/sec

(gas = m³/sec — liquid = l/sec — solid waste = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ if HEALTH MATE EXCEEDED	√ if ECOL MATE EXCEEDED	(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (G x LINE 3)
UNITS	μg/g	μg/g	μg/g	–	–	–	–	–	–	g/sec	g/sec
SSMS											
27/Li	41	0.70	0.75	59		55		✓	✓	3.29E3	3.07E3
28/Na	>1,000	1.6E3	N	>0.6		-				>3.3	-
29/K	>1,000	N	N	-		-				-	-
30/Rb	28	3.6E3	N	0.008		-				0.45	-
31/Ce	1	2.5E3	N	0.0004		-				0.02	-
32/Be	3	0.06	0.11	50		27		✓	✓	2.79E3	1.51E3
33/Mg	>1,000	1.8E2	1.7E2	>5.6		>5.9		✓	✓	3.12E2	3.29E2
34/Ca	>1,000	4.8E2	3.2E1	>2.1		>31		✓	✓	1.17E2	1.73E3
35/Sr	433	9.2E1	N	4.7		-		✓		2.62E2	-
36/Ba	>653	1.0E1	5.0	>65		>131		✓	✓	3.67E3	7.31E3
37/B	52	9.3E1	5.0E1	0.56		1.0				31.2	55.8
38/Al	>1,000	1.6E2	2.0	>6.3		>500		✓	✓	3.52E2	2.79E4
39/Ga	24	1.5E2	N	0.16		-				8.9	-

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL. E) 5a 2,065

ECOLOGICAL MATE BASED (Σ COL. G) 5b 1.019E6

(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF ENTRIES COMPARED TO MATES

HEALTH 6a ____

ECOLOGICAL 6b ____

7. TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL. K) 7a 1.154E5

ECOLOGICAL MATE BASED (Σ COL. L) 7b 5.689E7

(ENTER HERE AND AT LINE 8, FORM IA01)

TABLE E-3. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

Page 2 / 3

SOURCE/CONTROL OPTION Burlington

EFFLUENT STREAM NO. 301

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E × LINE 3)	(ECOLOGICAL BASED) (G × LINE 3)
UNITS	µg/g	µg/g	µg/g	—	—	—	—	—	—	g/sec	g/sec
40/In	Internal	Standard									
41/Tl	<0.2	3.0	N	<0.07		-				<3.9	-
42/C	Not Reported										
43/Si	>1,000	3.0E2	N	>3.3		-		✓		>1.84E2	-
44/Ge	5	1.7E1	N	0.29		-				16.2	-
45/Sn	1.2	N	N	-		-				-	-
46/Pb	7	0.50	0.10	14		70		✓	✓	7.81E2	3.91E3
48/P	>1,000	3.0E1	0.001	>33		>1.0E6		✓	✓	>1.84E3	>5.58E7
49/As	72	0.50	0.10	144		72		✓	✓	8.04E3	4.02E3
50/Sb	2	1.5E1	0.40	0.13		5			✓	7.3	2.79E2
51/Bi	<0.2	1.2E1	N	<0.02		-				<1.1	-
53/S	>1,000	N	N	-		-				-	-
54/Se	9	0.10	0.05	90		180		✓	✓	5.02E3	1.0E4
55/Te	<0.2	3.0	N	<0.07		-				<3.9	-
56/F	473	7.5E1	N	6.3		-		✓		3.52E2	-
57/Cl	108	2.6E3	0.01	0.04		1.1E4				2.2	6.14E5
58/Br	20	N	N	-		-				-	-
59/I	2	N	N	-		-				-	-
60/Sc	12	1.6E3	N	0.008		-				0.45	-
61/Y	26	3.0E1	N	0.87		-				48.5	-
62/Ti	>1,000	1.8E2	N	>5.6		-		✓		>3.13E2	-
63/Zr	79	1.5E1	N	5.3		-		✓		2.96E2	-
64/Hf	<0.7	1.5	N	<0.47		-				<26.2	-
65/V	143	5.0	0.30	29		477		✓	✓	1.62E3	2.66E4
66/Nb	11	6.5E2	N	0.02		-				1.1	-

TABLE E-3. (continued)

Page 3 / 3

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

SOURCE/CONTROL OPTION Burlington

EFFLUENT STREAM NO 302

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCEN TRATION	HEALTH MATE CONCEN TRATION	ECOLOGICAL MATE CONCEN TRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E × LINE 3) g/sec	(ECOLOGICAL BASED) (G × LINE 3) g/sec
UNITS	µg/g	µg/g	µg/g	—	—	—	—	—	—		
67/Ta	<0.2	1.5E2	N	<0.001		-				<0.06	-
68/Cr	110	0.50	0.50	220		220		✓	✓	1.23E4	1.23E4
69/Mo	23	1.5E2	1.4E1	0.15		1.6			✓	8.4	89
70/W	<0.2	3.0E1	N	<0.007		-				<0.39	-
71/Mn	447	0.50	0.20	894		2,235		✓	✓	4.99E4	1.25E5
72/Fe	>1,000	3.0	0.50	>333		>2,000		✓	✓	>1.86E4	>1.12E5
73/Ru	<0.2	N	N	-		-				-	-
74/Co	8.7	1.5	0.50	5.8		17		✓	✓	3.24E2	9.49E2
75/Rh	<0.2	0.03	N	<6.7		-		✓		<3.74E2	-
76/Ni	27	0.45	0.02	60		1,350		✓	✓	3.35E3	7.53E4
77/Pt	<0.2	0.06	N	<3.3		-				<1.84E2	-
78/Cu	64	1.0E1	0.10	6.4		640		✓	✓	3.57E2	3.57E4
79/Ag	<0.2	0.50	0.10	<0.4		<2			✓	<22.3	<1.12E2
80/Au	<0.2	N	N	-		-				-	-
81/Zn	70	5.0E1	0.20	1.4		350		✓	✓	78	1.95E4
82/Cd	≤0.47	0.10	0.002	≤4.7		≤235		✓	✓	262	1.31E4
83/Hg	0.66	0.02	0.50	3.3		1.3		✓	✓	1.84E2	72.5
84/La	23	3.4E3	N	0.007		-				0.39	-

TABLE E-4. SECONDARY COLLECTOR ASH WORKSHEET

SAM/IA WORKSHEET FOR LEVEL 1 **Form IA02 Level 1**

1. SOURCE/CONTROL OPTION

Page 1 / 3

Burlington Electric Wood and Oil Fired Boiler

2. EFFLUENT STREAM

303 Secondary Collector Ash

CODE # NAME

3. EFFLUENT STREAM FLOW RATE

Q = 1.55 g/sec

(gas = m^3/sec — liquid = l/sec — solid waste = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E × LINE 3)	(ECOLOGICAL BASED) (G × LINE 3)
UNITS	μg/g	μg/g	μg/g	—	—	—	—	—	—	g/sec	g/sec
SSMS											
27/Li	57	0.70	0.75	81		76		√	√	1.26E2	1.18E2
28/Na	>1,000	1.6E3	N	0.63		-				0.98	-
29/K	>1,000	N	N	-		-				-	-
30/Rb	66	3.6E3	N	0.02		-				0.03	-
31/Ce	4.3	2.5E3	N	0.002		-				0.003	-
32/Be	6	0.06	0.11	100		55		√	√	1.55E2	85.3
33/Mg	>1,000	1.8E2	1.7E2	5.6		5.9		√	√	8.7	9.2
34/Ca	>1,000	4.8E2	3.2E1	2.1		33		√		3.3	51.2
35/Sr	>1,000	9.2E1	N	11		-		√		17.1	-
36/Ba	>1,000	1.0E1	5.0	100		200		√	√	1.55E2	3.1E2
37/B	200	9.3E1	5.0E1	2.2		4		√	√	3.4	6.2
38/Al	>1,000	1.6E2	2.0	6.3		500		√	√	9.8	775
39/Ga	156	1.5E2	N	1.0		-				1.6	-

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD
HEALTH MATE BASED (Σ COL. E) 5a 6.961E3
ECOLOGICAL MATE BASED (Σ COL. G) 5b 1.072E6
(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF ENTRIES COMPARED TO MATES
HEALTH 6a ______
ECOLOGICAL 6b ______

7. TOXIC UNIT DISCHARGE SUM
HEALTH MATE BASED (Σ COL. K) 7a 1.073E4
ECOLOGICAL MATE BASED (Σ COL. L) 7b 1.658E6
(ENTER HERE AND AT LINE 8, FORM IA01)

TABLE E-4. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1 Page 2 / 3

SOURCE/CONTROL OPTION Burlington EFFLUENT STREAM NO 303

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E × LINE 3)	(ECOLOGICAL BASED) (G × LINE 3)
UNITS	µg/g	µg/g	µg/g	—	—	—	—	—	—	g/sec	g/sec
40/In	Internal Standard										
41/Tl	< 0.6	3.0	N	0.02		-				0.03	-
42/C	Not Reported							✓			
43/Si	>1,000	3.0E2	N	3.3		-				5.1	-
44/Ge	29	1.7E1	N	1.7		-		✓		2.6	-
45/Sn	5	N	N	-		-				-	-
46/Pb	4	0.50	0.10	8		40		✓	✓	1.2	62
48/P	>1,000	3.0E1	0.001	33		1.0E6		✓	✓	51.2	1.55E6
49/As	650	0.50	0.10	1.3E3		6.5E3		✓	✓	2.02E3	1.0E4
50/Sb	14	1.5E1	0.40	0.93		35			✓	1.4	54.3
51/Bi	<0.6	1.2E1	N	0.05		-				0.08	-
53/S	>1,000	N	N	-		-				-	-
54/Se	98	0.10	0.05	980		1,960		✓	✓	1.52E3	3.04E3
55/Te	<0.8	3.0	N	0.27		-				0.42	-
56/F	>1,000	7.5E1	N	13		-		✓		20.2	-
57/Cl	350	2.6E3	0.01	0.14		3.5E4			✓	0.22	5.43E4
58/Br	28	N	N	-		-				-	-
59/I	4.3	N	N	-		-				-	-
60/Sc	58	1.6E3	N	0.04		-				0.06	-
61/Y	112	3.0E1	N	3.7		-		✓		5.7	-
62/Ti	>1,000	1.8E2	N	33		-		✓		51.2	-
63/Zr	170	1.5E1	N	11		-		✓		17.1	-
64/Hf	<3.5	1.5	N	2.3		-		✓		3.6	-
65/V	>630	5.0	0.30	126		2.1E3		✓	✓	195	-
66/Nb	56	6.5E2	N	0.09		-				0.14	-

TABLE E-4. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

Page 3 / 3

SOURCE/CONTROL OPTION Burlington

EFFLUENT STREAM NO 303

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (G x LINE 3)
UNITS	μg/g	μg/g	μg/g	—	—	—	—	—	—	g/sec	g/sec
67/Ta	<0.6	1.5E2	N	0.004		-				0.006	-
68/Cr	374	0.50	0.50	748		748		✓	✓	1.16E3	1.16E3
69/Mo	39	1.5E2	1.4E1	0.26		2.8			✓	0.40	4.3
70/W	3.7	3.0E1	N	0.12		-				0.19	-
71/Mn	>1,000	0.50	0.20	2.0E3		5.0E3		✓	✓	3.1E3	7.75E3
72/Fe	>1,000	3.0	0.50	333		2.0E3		✓	✓	5.16E2	3.1E3
73/Ru	<0.6	N	N	-		-				-	-
74/Co	57	1.5	0.50	38		114		✓	✓	5.9	1.77E2
75/Rh	<0.6	0.03	N	20		-		✓		31	-
76/Ni	297	0.45	0.02	660		1.49E4		✓	✓	1.02E3	2.31E4
77/Pt	<0.6	0.06	N	10		-		✓		15.5	-
78/Cu	160	1.0E1	0.10	16		1.6E3		✓	✓	24.8	2.48E3
79/Ag	<0.6	0.50	0.10	1.2		6		✓	✓	1.9	9.3
80/Au	<0.6	N	N	-		-				-	-
81/Zn	89	5.0E1	0.20	1.8		445		✓	✓	2.8	6.90E2
82/Cd	1.3	0.10	0.002	13		650		✓	✓	20.2	1.01E3
83/Hg	5.9	0.02	0.50	295		12		✓	✓	4.57E2	18.6
84/La	85	3.4E3	N	0.03		-				0.05	-
PAH											
Acenaphthylene	2.3	N	N	-		-				-	-
Phenanthrene	6.5	4.8E1	N	0.14		-				0.22	-
Fluoranthene	1.9	2.8E3	N	0.0007		-				0.001	-
Pyrene	0.74	6.9E3	N	0.001		-				0.002	-

TABLE E-5. STACK EMISSIONS WORKSHEET

SAM/IA WORKSHEET FOR LEVEL 1

Form IA02 Level 1

Page 1 / 6

1. SOURCE/CONTROL OPTION

Burlington Electric Wood and Oil Fired Boiler

2. EFFLUENT STREAM

101 Stack Emissions

CODE # NAME

3. EFFLUENT STREAM FLOW RATE

Q = 21.1 cu m/sec

(gas = m³/sec — liquid = l/sec — solid waste = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E × LINE 3)	(ECOLOGICAL BASED) (G × LINE 3)
UNITS	μg/cu m	μg/cu m	μg/cu m	—	—	—	—	—	—	cu m/sec	cu m/sec
CO	2.43E5	4.0E4	1.2E5	6.1		2.0		√	√	129	42
SO_2	3.59E5	1.3E4	N	28		-		√		591	-
NO_x (NO_2)	1.24E5	9.0E3	N	14		-		√		295	-
SSMS of Method 5 Particulate											
27/Li	5.1	2.2E1	N	0.23		-				4.9	-
28/Na	a/	5.3E4	N	-		-				-	-
29/K	a/	N	N	-		-				-	-
30/Rb	8.0	1.2E5	N	6.7E5		-				1.4E3	-
31/Ge	0.32	8.2E4	N	3.9E6		-				8.2E5	-
32/Be	<0.28	2.0	N	<0.14		-				<3.0	-
33/Mg	a/	6.0E3	N	-		-				-	-
34/Ca	a/	1.6E4	N	-		-				-	-
35/Sr	>63	3.1E3	N	>0.02		-				>0.42	-

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD
HEALTH MATE BASED (Σ COL. E) 5a 178.6
ECOLOGICAL MATE BASED (Σ COL. G) 5b 15.9
(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF ENTRIES COMPARED TO MATES
HEALTH 6a ______
ECOLOGICAL 6b ______

7. TOXIC UNIT DISCHARGE SUM
HEALTH MATE BASED (Σ COL. K) 7a 3.763E3
ECOLOGICAL MATE BASED (Σ COL. L) 7b 334.3
(ENTER HERE AND AT LINE 8, FORM IA01)

TABLE E-5. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1 Page 2 / 6

SOURCE/CONTROL OPTION Burlington EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E × LINE 3)	(ECOLOGICAL BASED) (G × LINE 3)
UNITS	µg/cu m	µg/cu m	µg/cu m	—	—	—	—	—	—	cu m/sec	cu m/sec
36/Ba	>95	5.0E2	N	>0.19		-				>4.0	-
37/B	a/	3.1E3	N	-		-				-	-
38/Al	a/	5.2E3	N	-		-				-	-
39/Ga	33	5.0E3	N	6.6E3		-				0.14	-
41/Tl	<0.03	1.0E2	N	<3.0E4		-				<6.3E3	-
43/Si	a/	1.0E4	N	-		-				-	-
44/Ge	8.7	5.6E2	N	0.02		-				0.42	-
45/Sn	2.6	N	N	-		-				-	-
46/Pb	>69	1.5E2	N	>0.46		-				>9.7	-
48/P	>104	1.0E2	N	>1.0		-				>21	-
49/As	50	2.0	N	25		-		✓		528	-
50/Sb	2.9	5.0E2	N	5.8E3		-				0.12	-
51/Bi	<0.06	41.E2	N	<1.5E4		-				<3.2E3	-
53/S	a/	N	N	-		-				-	-
54/Se	29	2.0E2	N	0.15		-				3.2	-
55/Te	<0.03	1.0E2	N	<3.0E4		-				<6.3E3	-
56/F	a/	2.5E3	N	-		-				-	-
57/Cl	a/	N	N	-		-				-	-
58/Br	28	N	N	-		-				-	-
59/I	2.5	N	N	-		-				-	-
60/Sc	1.1	5.3E4	N	2.1E5		-				4.4E4	-
61/Y	1.9	1.0E3	N	1.9E3		-				0.04	-
62/Ti	>100	6.0E3	N	>0.02		-				>0.42	-
63/Zr	8.3	5.0E3	N	1.7E3		-				0.04	-
64/Hf	<0.03	5.0E2	N	<6.0E5		-				<1.3E3	-

TABLE E-5. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1 Page 3 / 4

SOURCE/CONTROL OPTION Burlington EFFLUENT STREAM NO. 101

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	DECIMAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	DECIMAL POSITION IN ECOL. MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL. MATE EXCEEDED	HEALTH BASED (E x LINE 3)	ECOLOGICAL BASED (G x LINE 3)
UNITS	µg/cu m	µg/cu m	µg/cu m	—	—	—	—	—	—	cu m/sec	cu m/sec
65/V	13	5.0E2	1.0	0.03		13			✓	0.63	274
66/Nb	1.1	2.4E4	N	4.6E5		-				9.7E4	-
67/Ta	<0.03	5.0E3	N	<6.0E6		-				<1.3E4	-
68/Cr	<0.016	1.0	N	<0.02		-				<0.42	-
69/Mo	3.3	5.0E3	N	6.6E4		-				0.014	-
70/W	<0.03	1.0E3	N	<3.0E5		-				<6.3E4	-
71/Mn	56	5.0E3	N	0.01		-				0.21	-
72/Fe	>104	1.0E3	N	>0.10		-				>7.1	-
73/Ru	<0.03	N	N	-		-				-	-
74/Co	<0.2	5.0E1	N	<4.0E3		-				<0.08	-
75/Rh	<0.03	1.0	N	<0.03		-				<0.63	-
76/Ni	25	1.5E1	N	1.7		-		✓		36	-
77/Pt	<0.03	2.0	N	<0.02		-				<0.42	-
78/Cu	55	2.0E2	N	0.28		-				5.9	-
79/Ag	1.8	1.0E1	N	0.18		-				3.8	-
80/Au	<0.03	N	N	-		-				-	-
81/Zn	>100	4.0E3	N	>0.03		-				>0.63	-
82/Cd	7.3	1.0E1	N	0.73		-				1.5	-
83/Hg	7.7	5.0E1	1.0E1	0.15		0.77				3.2	16
84/La	4.4	1.1E5	N	4.0E5		-				8.4E4	-
SASS XAD-2 Resin Extract											
LC1	0.11	100	N	0.001		-				0.02	-
LC2	0.006	110	N	5.5E5		-				0.001	-
LC3	1.2	0.02	N	60		-		✓		1.27E3	-

TABLE E-5. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

Page 4 / 6

SOURCE/CONTROL OPTION Burlington

EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL. MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E × LINE 3)	(ECOLOGICAL BASED) (G × LINE 3)
UNITS	μg/cu m	μg/cu m	μg/cu m	—	—	—	—	—	—	cu m/sec	cu m/sec
LC4	0.011	990	N	1.1E5		-				2.3E4	-
LC5	-	1.3E3	N	-		-				-	-
LC6	8.2	170	N	0.05		-				1.1	-
LC7	7.4	100	N	0.07		-				1.5	-
SSMS of Aqueous Condensate and Peroxide Impinger											
27/Li	0.011	2.2E1	N	5.0E4		-				0.011	-
28/Na	5.2	5.3E4	N	9.8E5		-				2.1E3	-
29/K	1.4	N	N	-		-				-	-
30/Rb	<0.009	1.2E5	N	<7.5E8		-				1.6E6	-
31/Ce	<0.009	8.2E4	N	<1.1E7		-				2.3E6	-
32/Be	<0.009	2.0	N	<4.5E3		-				0.095	-
33/Mg	1.4	6.0E3	N	2.3E4		-				4.8E3	-
34/Ca	19	1.6E4	N	1.2E3		-				0.025	-
35/Sr	0.09	3.1E3	N	2.9E5		-				6.1E4	-
36/Ba	0.05	5.0E2	N	1.0E4		-				2.1E3	-
37/B	0.32	3.1E3	N	1.0E4		-				2.1E3	-
38/Al	0.54	5.2E3	N	1.0E4		-				2.1E3	-
39/Ga	0.11	5.0E3	N	2.2E5		-				4.6E4	-
41/Tl	<0.009	1.0E2	N	<9.0E5		-				1.9E3	-
43/Si	11	1.0E4	N	1.1E3		-				0.023	-
44/Ge	<0.009	5.6E2	N	1.6E5		-				3.4E4	-
45/Sn	0.16	N	N	-		-				-	-
46/Pb	1.6	1.5E2	N	6.7E4		-				0.014	-
47/P	6.2	1.0E2	N	0.06		-				1.3	-

TABLE E-5. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1 Page 5 / 6

SOURCE/CONTROL OPTION Burlington EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E × LINE 3)	(ECOLOGICAL BASED) (G × LINE 3)
UNITS	μg/cu m	μg/cu m	μg/cu m	—	—	—	—	—	—	cu m/sec	cu m/sec
49/As	0.21	2.0	N	0.11		-				2.3	-
50/Sb	0.003	5.0E2	N	6.0E6		-				1.3E4	-
51/Bi	<0.009	4.1E2	N	<2.2E5		-				<4.6E4	-
53/S	>24	N	N	-		-				-	-
54/Se	0.13	2.0E2	N	6.5E4		-				0.014	-
55/Te	<0.009	1.0E2	N	<9.0E5		-				<1.9E3	-
56/F	2.2	2.5E3	N	8.8E4		-				0.019	-
57/Cl	5.4	N	N	-		-				-	-
58/Br	0.25	N	N	-		-				-	-
59/I	0.02	N	N	-		-				-	-
60/Sc	<0.002	5.3E4	N	<3.8E8		-				<8.0E7	-
61/Y	<0.009	1.0E3	N	<9.0E6		-				<1.9E4	-
62/Ti	0.51	6.0E3	N	8.5E5		-				1.8E3	-
63/Zr	<0.014	5.0E3	N	<2.8E6		-				<5.9E5	-
64/Hf	<0.009	5.0E2	N	<1.8E5		-				<3.8E4	-
65/V	0.11	5.0E2	1.0	2.2E4		0.11				4.6E3	2.3
66/Nb	0.029	2.4E4	N	1.2E6		-				2.5E5	-
67/Ta	<0.009	5.0E3	N	<1.8E6		-				<3.8E5	-
68/Cr	>38	1.0	N	>38		-		✓		>802	-
69/Mo	1.5	5.0E3	N	3.0E4		-				6.3E3	-
70/W	<0.009	1.0E3	N	<9.0E6		-				<1.9E4	-
71/Mn	5.4	5.0E3	N	1.1E3		-				0.023	-
72/Fe	>59	1.0E3	N	>0.06		-				>1.3	-
73/Ru	<0.009	N	N	-		-				-	-
74/Co	0.88	5.0E1	N	0.018		-				0.38	-

TABLE E-5. (continued)

CONTINUATION SHEET FOR ITEM NO. 4, FORM IA02, LEVEL 1

Page 6 / 6

SOURCE/CONTROL OPTION Burlington

EFFLUENT STREAM NO 101

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ if HEALTH MATE EXCEEDED	√ if ECOL MATE EXCEEDED	(HEALTH BASED) (E × LINE 3)	(ECOLOGICAL BASED) (G × LINE 3)
UNITS	µg/cu m	µg/cu m	µg/cu m	—	—	—	—	—	—	cu m/sec	cu m/sec
75/Rh	<0.009	1.0	N	<9.0E3		-				<0.19	-
76/Ni	>25	1.5E1	N	>1.7		-			✓	>35.9	-
77/Pt	<0.009	2.0	N	<4.5E3		-				<0.095	-
78/Cu	>16	2.0E2	N	>0.08		-				>1.7	-
79/Ag	0.029	1.0E1	N	2.9E3		-				0.061	-
80/Au	<0.009	N	N	-		-				-	-
81/Zn	>16	4.0E3	N	>4.0E3		-				0.084	-
82/Cd	0.013	1.0E1	N	1.3E3		-				0.027	-
83/Hg	0.009	5.0E1	1.0E1	1.8E4		9.0E4				0.031	-
84/La	<0.009	1.1E5	N	<8.2E8		-				1.7E6	-

---

a/ Concentration was not reported due to high background interferences.